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MANAGING LARGE ENERGY AND MINERAL RESOURCES (EMR) PROJECTS IN CHALLENGING ENVIRONMENTS

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MANAGING LARGE ENERGY AND MINERAL RESOURCES (EMR) PROJECTS IN CHALLENGING ENVIRONMENTS

by

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Dedication

To my family, with their unconditional love, dedication, and encouragement,
I have the greatest love and appreciation for their support.

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MANAGING LARGE ENERGY AND MINERAL RESOURCES (EMR) PROJECTS IN CHALLENGING ENVIRONMENTS

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The viability of energy mineral resources (EMR) construction projects is contingent upon the state of the world economic climate. Oil sands projects in Alberta, Canada exemplify large EMR projects that are highly sensitive to fluctuations in the world market. Alberta EMR projects are constrained by high fixed production costs and are also widely recognized as one of the most challenging construction projects to successfully deliver due to impacts from extreme weather conditions, remote locations and issues with labor availability amongst others. As indicated in many studies, these hardships strain the industry's ability to execute work efficiently, resulting in declining productivity and mounting cost and schedule overruns. Therefore, to enhance the competitiveness of Alberta EMR projects, project teams are targeting effective management strategies to enhance project performance and productivity by countering the uniquely challenging environment in Alberta.

The main purpose of this research is to develop industry wide benchmarking tailored to the specific constraints and challenges of Alberta. Results support quantitative assessments and identify the root causes of project performance and ineffective field productivity problems in the heavy industry sector capital projects. Customized metrics produced from the data collected through a web-based survey instrument were used to quantitatively assess project performance in the following dimensions: cost, schedule, change, rework, safety, engineering and construction productivity and construction practices. The system enables the industry to measure project performance more accurately, get meaningful comparisons, while establishing credible norms specific to Alberta projects.

Data analysis to identify the root cause of performance problems was conducted. The analysis of Alberta projects substantiated lessons of previous studies to create an improved awareness of the abilities of Alberta-based companies to manage their unique projects. This investigation also compared Alberta- based projects with U.S. projects to point out the differences in project process and management strategies under different environments. The relative impact of factors affecting construction productivity were identified and validated by the input from industry experts. The findings help improve the work processes used by companies developing projects in Alberta.

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CHAPTER 1: INTRODUCTION

1.1 RESEARCH MOTIVATION

The viability of energy mineral resources (EMR) construction projects is contingent upon the state of the world economic climate. As a result, the cost effectiveness of these capital projects is critical at project signoff and throughout the project in an effort to avoid work stoppages. Oil sands projects in Alberta, Canada exemplify large EMR projects which are highly sensitive to fluctuations in the world market. Alberta-based EMR projects are constrained due to high fixed production costs. Therefore, to enhance the cost effectiveness of these projects and sustain them under economic turbulence and sharp declines in energy demand, project teams are targeting effective management strategies to enhance Alberta construction project performance.

Alberta oil sands projects are widely recognized as one of the most challenging types of construction projects to successfully deliver. These projects are characterized by their mega project size with a budget of over $500 million executing under extremely burdensome factors such as issues with labor availability, remote site location, and harsh weather conditions. Construction labor is predominately unionized and highly skilled, but in increasingly short supply. The projects are remotely located and most of them require that workers be housed in camps, generally working 60 hours a week or more. Severe weather is another large challenge as inclement weather is common for four to five months of the year. These hardships have strained the industry's ability to execute work efficiently and have led to significant concerns regarding declining productivity and mounting cost and schedule overruns as indicated by many studies (Lessard, 2001; Merrow, 2003; Smyth, 2004; COAA and CCIC, 2006). Therefore, the need for implementing adaptive project management techniques to counter the uniquely challenging environment in Alberta has become critical to the advancement of oil sands project performance and work force productivity.

Although anecdotal evidence indicates an Alberta Oil Sands project would likely exhibit a 5% to 20% increase in cost and suffer worse productivity by a factor of three, than a U.S. project, there are no public data available to confirm or refute this notion. At present, blame for the shortfalls of Alberta Oil Sands projects has fallen squarely on unproductive field labor; however, there is no concrete evidence to support the claim that it is the sole cause behind the problems. This study asserts that cost drivers in Alberta in fact come from a combination of factors, productivity being only one. Other factors such as project characteristics, project execution strategies, and environmental challenges also share the blame. Project characteristics are inherent factors; for example, mega project size is known to have high cost overruns and schedule delays as documented by Robinson (2005). Projects in remote locations, which require high indirect work hours, also contribute to the hardships faced by Alberta Oil Sands projects. In addition, there are more easily controlled factors, such as project execution which project teams can employ strategies to create value to positively influence project outcome. While many studies have been conducted on Alberta based projects, there is a lack of quantitative assessments and analyses defining the relative impact of the aforementioned factors on Alberta Oil Sands project.

With the concerns mentioned above, the Construction Owner Association of Alberta (COAA) and its members have been motivated to improve project performance with due consideration to the specific constraints and challenges particular to Alberta. They recognized that the industry needs a standardized, yet customized data collection system to assess project performance and productivity while specifically accounting for the unique characteristics of Alberta's mega projects. The immediate benefit of implementing a benchmarking system is achieving an understanding of the root causes behind the low project performance and ineffective field productivity exhibited in past projects. Then, the industry-wide benchmarking enables organizations to measure project performance more accurately, get meaningful comparisons, establish credible norms for project performance and drive continuous improvement in capital facilities programs. Ultimately, this research will provide a benchmarking system and analyses for information to organizations to adopt more effective project execution strategies that enhance competitiveness.

1.2 RESEARCH PURPOSE AND OBJECTIVES

The main purpose of this research is to identify the root causes of project performance problems and ineffective field productivity on Alberta Oil Sands projects. Specific objectives of this research include:

1) Developing metrics and a performance measurement system tailored to the specific constraints and challenges in Alberta
2) Establishing a project performance reporting system that provides valuable information and meets the needs of the industry
3) Demonstrating differences in field productivity and overall project performance between Alberta and typical U.S. projects

4) Examining the relationship between project characteristics, practices, productivity and overall project performance
5) Identifying factors impacting field productivity on Alberta projects
6) Assessing the relative impact of significant factors impacting field productivity on Alberta projects.

1.3 RESEARCH HYPOTHESES

To meet the research objectives stated in Section 1.2, the following three research hypotheses were established and proven in this study:

Hypothesis 1: Metrics for measuring project performance specific to constraints and challenging environments for Alberta projects can be developed and assessed.

The first hypothesis states that metrics for measuring project performance, field productivity, and best practice implementation specific to Alberta projects can be developed. The criteria for these metrics were ascertained by expert opinions and data analysis results. Fundamentally, the metrics should be a simple, understandable, and quantifiable measure, capable of illustrating relationship to other project performance outcome and providing industry norms to enhance project performance.

Hypothesis 2: Factors impacting project performance and productivity can be identified.

This hypothesis establishes that the factors impacting project cost, schedule performance, and field productivity rates in Alberta can be identified. The results will also help identify the root causes of high project cost overrun and schedule delays and shed light on whether the project setbacks are mainly caused by unproductive field labor, intrinsic project characteristics, management strategies, or other challenging factors such as severe weather, site location, availability of skilled workforce, and material availability.

Hypothesis 3: The relative impact of factors that influence field productivity on Alberta projects can be assessed.

This hypothesis establishes that the relative impact of major factors affecting a project's field productivity can be assessed. The factors identified in the second hypothesis were quantified by assessing the dependencies on the impact of factors. This ultimately provides a productivity adjustment based on the expected condition of a project in a given environment. The result will allow estimators to more accurately develop productivity estimates.

1.4 RESEARCH SCOPE

The scope of this research is defined below:

1) Analysis is limited to large energy and mineral resources (EMR) projects with a total project cost greater than $5M USD[1]. The EMR project includes chemical manufacturing, mining, power generation, oil exploration/ production, natural gas, oil refining and pipelines.
2) The research is focused on measurements for capital facility delivery performance and not operations.
3) The dataset analyzed is provided by CII and COAA projects only. Projects in the U.S., which are included in the CII database, will be

[1] CII large projects definition

considered U.S. projects, while Canadian projects submitted to the COAA project database will be identified as Alberta-based projects.

4) Economic, social, political, and regulatory climates surrounding Alberta projects are not directly assessed.

1.5 ORGANIZATION OF DISSERTATION

This dissertation consists of eight chapters. The first chapter includes an overview of existing problems, industry need, research objectives and scope. Chapter 2 provides an overview of previous studies regarding metric development and benchmarking systems for energy related industries, issues relating to project performance, and the causes behind Alberta project problems. Chapter 3 describes the research methodology and data analysis approach employed in this study in addition to indicating research milestones. Chapter 4 outlines the key development of Alberta metrics and benchmarking systems. Chapters 5 to 7 present the data analysis used for this research. Chapter 5 focuses on analysis of Alberta metrics consisting of descriptive statistics of project performance metrics for Alberta projects including comparisons between Alberta and U.S. projects, while Chapter 6 mainly presents analysis of project performance by project characteristics, and management/ best practices. Then, Chapter 7 provides more detail on the analysis of impact factor affecting project performance and construction productivity on Alberta projects. Finally, Chapter 8 consists of concluding remarks, contributions, and recommendations resulting from this research effort.

CHAPTER 2: RESEARCH BACKGROUND

2.1 CII/ COAA BENCHMARKING PROGRAM INITIATIVE

Benchmarking has long been used as a tool to discover ways to improve the performance of organizations in the manufacturing industry. It is defined as a continuous, systematic process of measuring one's performance against results from recognized leaders, for the purpose of determining best practices that lead to superior performance when adapted and implemented (CII, 2002). In the construction industry, benchmarking is primarily used at the project level due to the project oriented nature of construction. Benchmarking can help organizations identify gaps in their performance when compared to their peers: internally, externally and across industries. Ultimately, it helps organizations establish improvement goals, and enables them to understand and achieve "best in class" performance.

The Construction Industry Institute (CII), based at The University of Texas at Austin is a consortium of leading owners, engineering and construction contractors, and suppliers that have come together to improve the cost effectiveness on capital projects. As a major public benchmarking resource in construction, CII maintains a statistically credible program entitled Benchmarking & Metrics (BM&M) that provides industry performance norms, quantifies the use and value of best practices, and produces a means for companies to benchmark project performance, productivity, and practice use against a large number of projects from industry.

The Construction Owners Association of Alberta (COAA) is an association of owners, construction and engineering contractors, and governmental and labor groups to develop construction best practices that improve the construction industry's project performance in Alberta, Canada. With consideration given to the unique characteristics and factors influencing major energy related projects in Alberta, the COAA benchmarking committee and the government of Alberta, in conjunction with the CII BM&M team created the "COAA Alberta Major Projects Benchmarking and Metrics Program" to guide COAA members in the development of construction processes on major projects. This jointly sponsored program forms the basis of this research study.

2.2 CII BENCHMARKING SYSTEM AND PERFORMANCE METRICS

This research utilized the CII benchmarking system, which is a web-based system of data collection, performance reporting, and industry analysis. Project data are collected through an online survey instrument, gathering information on project participation, environment, cost, schedule, practice use, and engineering and construction productivity. CII has developed a set of metrics to measure project performance as follows.

2.2.1 Project Performance Metrics

CII project performance metrics measure 1) cost, 2) schedule, 3) construction safety, 4) changes, and 5) rework. Project cost and schedule performance metrics evaluate the degree of cost and schedule deviation incurred compared to baseline estimates for both the project overall and the project phases.

Phase cost and schedule metrics determine the proportion of the total project cost and duration expended per phase. Safety, changes, and rework are measured in terms of overall project performance at project completion. The definitions of these metrics are described in Appendix B.

2.2.2 Engineering and Construction Productivity System and Metrics

This research also made use of the CII construction and engineering productivity systems (CPMS and EPMS) developed by CII, Park (2005), and Kim (2007). In the aforementioned studies, metrics were defined as ratios between work hours (WH) and quantities, which were proven to be a reliable assessment that is easily understood and consistent with contractor estimates and cost accounting systems. In this system, a lower productivity rate indicates better performance.

In 2005, CII and Park developed construction productivity metrics and defined them as labor productivity measured in actual direct work hours required to install a unit quantity, as shown in Equation 1. Productivity rates are captured for the following substantial work activities defined by CII: 1) concrete, 2) structural steel, 3) equipment, 4) piping, 5) electrical, 6) instrumentation, and 7) insulation. A complete definition of labor direct work hours for construction productivity is provided in the questionnaire in Appendix G.

$$\text{Construction Productivity} = \frac{\text{Input}}{\text{Output}} \frac{\text{Actual Installed Direct Work Hours}}{\text{Installed Quantity}} \quad \text{[Equation 1]}$$

The engineering productivity metric system (EPMS) is also quantity-based and was developed by CII and Kim (2007). These metrics were defined as actual engineering work hours per issued for construction (IFC) quantity, which is the number of actual direct work hours required to design a unit of work, as shown in Equation 2. Data are captured for significant work activities by the following selected design disciplines: 1) concrete, 2) structural steel, 3) equipment, 4) piping, 5) electrical, and 6) instrumentation. A definition of direct work hours for the engineering productivity system is shown in the questionnaire in Appendix G.

$$Engineering\ Productivity = \frac{Input}{Output}\ \frac{Actual\ Design\ Work\ Hours}{IFC\ Quantity} \qquad \text{[Equation 2]}$$

Both the CPMS and EPMS consist of a set of metrics classified into disciplines. The hierarchically arranged metrics were established to roll up from level IV (element level) to level III (sub-category), level II (major category), and finally to level I (project level) as illustrated in Figure 2.1. Subsequently, the level I productivity index was constructed for engineering productivity and is called the EPM index, and construction productivity and is called the CPM index (Liao, 2008).

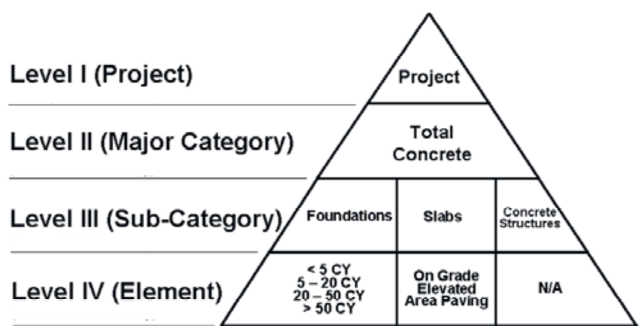

Figure 2.1 The CPMS Metric Hierarchy (Kim, 2007)

This research adopted the procedure for the development of the CPM index developed by Liao (2008) to measure project construction productivity and produce analyses in the following chapter. In brief, the level IV (element) metric was transformed by natural logarithm and normalized with z scores by using the average productivity rates and standard deviations of the transformed productivity at year 2004 as a basis. Next, the transformed level IV metrics were aggregated and weighted by their work hours. Thus, the construction index can be generalized in the following equation:

$$CPM = \frac{\sum_{i=1}^{n} \left(WH_{ip} \times z_{ip} \right)}{\sum_{i=1}^{n} WH_{ip}} \qquad \text{[Equation 3]}$$

where WH_{ip} is direct work hours of the i^{th} underlying metric in the p^{th} project, z_{ip} is the z score of the i^{th} underlying metric in the p^{th} project. Table 2.1 summarizes the construction productivity indices and their underlying metrics. Table 2.2 illustrates a sample calculation of the CPM index for the concrete and structural steel disciplines. The CPM index ranges between -3 and +3 where a negative value signifies better construction productivity than the norm, or that less effort necessary to finish a project when compared to the norm in the base year 2004 (Liao, 2008). As the CPM index shows in Table 2.2, the construction productivity of this project was slightly better than the norm by 0.12 time of standard deviation.

Table 2.1 Require Indices and Their Underlying Metrics (Liao, 2008)

Levels	Required Indices	Underlying Metrics
Discipline	Civil Index	Concrete, Steel (Level II)
	Electrical Index	Electrical Equipment, Conduit, Cable Tray, Wire & Cable, and Lighting (Level II)
Project	Project Index (Level I)	Concrete, Steel, Electrical Equipment, Conduit, Cable Tray, Wire & Cable, Lighting, Piping, Equipment, and Instrumentation (Level II)

Table 2.2 A CPM Index Development Example (Liao, 2008)

Disciplines	Hours (1)	Quantity	EP* (2)	Transformed EPM (3)	Mean of Transformed EPM in 2004 (4)	Standard Deviation of Transformed EP in 2004 (5)	Z score (6)
Concrete	5200	1700 (CY)	3.06	1.12	0.88	0.63	0.38
Steel	7500	800 (Ton)	9.38	2.24	2.47	0.49	-0.47
CPM Index (7)							-0.12
Calculations	(3)=ln(2) (6)=[(3)-(4)]/(5) (7)=[Σ ((1)*(6))]/[Σ(1)]						

2.3 ALBERTA PROJECT CHARACTERISTICS AND CHALLENGES

Potential factors, which may impact Alberta project performance are consolidated and categorized by this research into six major categories, as shown in Figure 2.2. These factors are aggregated from previous studies and are associated with the unique characteristics, and difficulties afflicting Alberta project performance and productivity. These factors were researched by including them in the benchmarking survey tool and project practitioners' surveys.

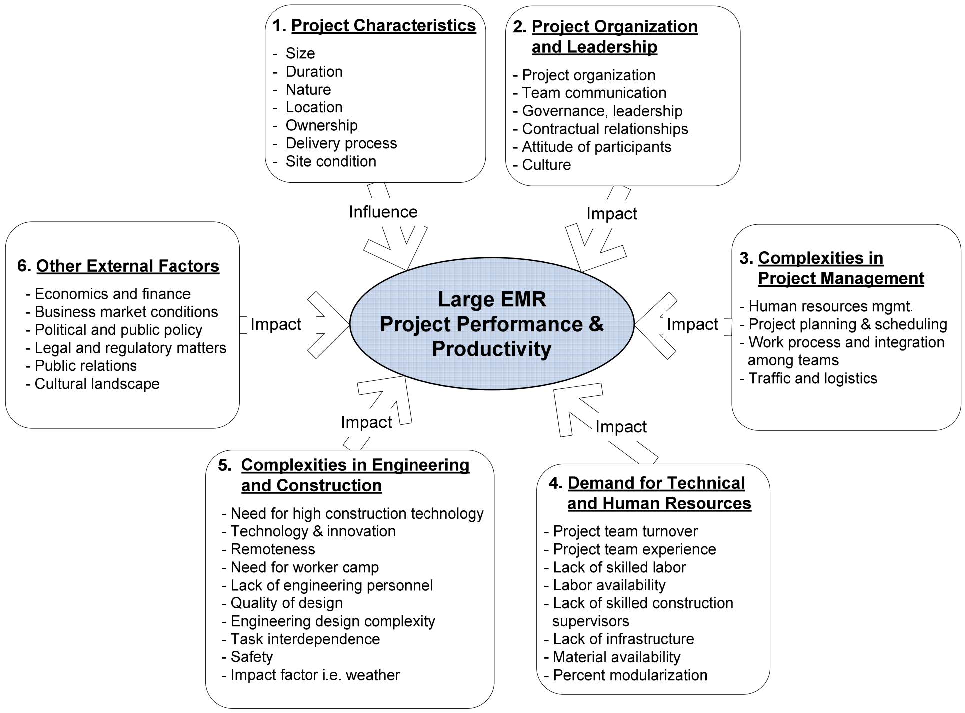

Figure 2.2 Aggregated Potential Factors Impacting Alberta Project Performance from Previous Studies

2.3.1 Project Characteristics

Generally, Alberta projects have a higher project capital cost, longer duration, and require more work hours than U.S. projects. In some cases, Alberta projects are located in remote areas, which lead to high complexity and a more uncertainty. Long project durations lead to high team turnover, extended overtime, and financial risks (Desnoyers, 1981; Anon, 2005). As a result, the problems experienced on Alberta projects are more pronounced than on smaller, perhaps more conventional, projects (Robinson, 2005). Frequently, large-scale projects are divided into multiple smaller projects to make them more manageable. Even so, each smaller project team requires facilities, expertise, resources, and management know how to handle the situation (Flyvbjerg, 2003; Fiori, 2005; Kerzner, 2006).

2.3.2 Project Organization and Leadership

Alberta projects are often much more intricate than U.S. projects with respect to project organization, internal communication, and contractual relationships (Edwards, 1982). Most Alberta projects require the involvement of multiple companies; fortunately, much of the work can be done through offsite engineering and modularization. Though necessary, collaboration is challenging and leads to additional complexity in interoperational relationships, project management, and engineering and construction methods (Tompkins, 1978; Edward, 1982; Flyvbjerg, 2003; Mochal, 2006; SMEC).

2.3.3 Complexities in Project Management

Managing and executing Alberta projects are more complex resulting in a need for high experience teams for high-quality front-end planning (Desnoyers, 1981; Edward, 1982; Kerzner, 2006), project cost and schedule control (Tompkins, 1978; Palmer and Mukherjee, 2006). Planning covers a broad range of human resources, task interdependency, project management, project control issues, traffic and logistics of materials, and resources.

2.3.4 Demand for Technical and Human Resources

Desnoyers (1981), Edwards (1982), Hendrickson (1998), Flyvbjerg (2003) and COAA have all pointed out difficulties in managing large EMR projects. They indicated the following potential causes of management difficulties: a) a lack of skilled laborers and construction supervisors, b) a shortage of qualified engineering designers and contractors, c) a lack of reputable and reliable vendors, d) insufficient quantities and poor quality of materials and equipment, and e) a lack of infrastructure to provide sufficient housing services and transportation for project personnel. Especially, Alberta projects require a great number of laborers, often for short periods, which are exacerbated when the project schedule slips and additional personnel must be hired to deliver the project.

2.3.5 Complexities in Engineering and Construction

Alberta projects often require advanced engineering techniques, experienced contractors, and reliable suppliers with sufficient planning and control of project cost, schedule, and construction execution. Due to complex construction procedures between work groups and multiple contractors, the integration of work and task interdependencies is a great challenge. These factors are even more difficult during expansion and upgrading efforts on Alberta projects when the production process must be interrupted for integration with incoming modular equipment.

2.3.6 Macroeconomics and Other External Factors

Alberta projects are greatly affected by macroeconomic factors, such as economic instability, business market conditions, inflation, exchange rate fluctuation, and other external factors including public policy, regulations, and cultural landscape (Desnoyers, 1981; Flyvbjerg, 2003; COAA). Generally, these factors influence both U.S. and Alberta projects; however, the impacts are magnified on Alberta projects. As Alberta projects are subjected to a higher degree of these risks and uncertainties, they tend to suffer from high cost overrun and schedule delay.

2.4 COMPANY BENCHMARKING AND METRICS

Benchmarking has been widely used in many industries (most notably manufacturing) as a process to make continuous improvements by comparison in order to achieve best in class performance. In the construction industry, most companies have implemented internal benchmarking processes and developed metrics to measure project delivery performance. Typically, these efforts have been attached to internal cost and schedule controls (Cox, Issa and Ahrens, 2003; CII, 2005; Lee, 2005).

In 1981, Desnoyers, a project manager at Exxon engineering, described in his research paper, both the implementation of benchmarking in Alberta to measure project performance in terms of cost and schedule by using internal norms. Exxon engineering benchmarked their productivity rate by using actual work hours from all types of construction work divided by internal norms. These methods facilitated the measurement of both work progress and overall productivity after project completion. Since then, most companies including Saudi Aramco, Shell Oil, Suncor Ltd., Imperial Oil, and Petro Canada have developed their internal benchmarking for their own measurements and have used them extensively.

Since these systems were developed by companies internally, the definition of terms to produce each metric is different. For example, some companies measure construction productivity in term of unit cost, while some measure productivity in work hours per unit quantity and include both direct and indirect effort. These discrepancies do not allow for meaningful external comparisons with others in the industry. Later, in 2005, the value of industry benchmarking was identified by Robinson, a professor at the University of Calgary. In her study, she declared the need for external benchmarking tailored to Alberta projects. Her study concluded that advantages of benchmarking would provide greater information to organizations by identifying opportunities for project performance improvement.

Similarly, COAA membership recognized the potential benefits of benchmarking, which led to the agreement with CII to develop specific benchmarking tailored to factors affecting project performance in the region. In this study, external benchmarking with metrics tailored to Alberta projects will be used to compare with other similar projects in the industry. Moreover, the results will provide quantitative documentation of the impacts that challenging factors have on Alberta project performance.

2.5 ASSESSMENT OF IMPACTS OF FACTORS INFLUENCING FIELD PRODUCTIVITY

Field productivity is generally recognized as a key determinant driving project cost and schedule. The variability of productivity from project to project can be driven by many factors. Below is a comprehensive list of from previous studies as well as factors consolidated by Schwartzkopf (1995), which are widely used to calculate labor productivity loss in construction claims.

a) Overtime and shift work (U.S. Dept. of Labor, 1947; U.S. Army Corps of Engineers, 1979; CPI, 1987; CII, 1988; NECA, 1989; Dozzi and Abourizk, 1993)
b) Acceleration (U.S. Army Corps of Engineers, 1979; NECA, 1987; AACE, 2004)
c) Effect of congestion on trades efficiency (Thomas and Smith, 1990)
d) Work sequencing and availability of materials and tools (Hanna, 1992; Thomas and Sakarcan, 1994).

e) Inefficiency and disruption (Thomas and Smith, 1990)

f) Labor demand (Fox 1978, Peltier 1978, Tucker 1986)

g) Effects of change orders (Leonard, 1987; Hanna, 2000; Ibbs, 2005)

h) Weather (Witrock, 1967; NECA, 1974; Wagner, 1974, Kuiper, 1976)

i) Learning curve effects (Ward and Thomas, 1984)

j) Project characteristics e.g. project size, complexity (NECA, 1975; Myer, 1984; Tucker, 1986)

k) Project management techniques, i.e. front end planning (RAND, 1981), engineering impact (Merrow, 1981), and material management (Thomas and Sanders, 1989)

l) Overstaffing (U.S. Army Corps of Engineers, 1979; Dozzi and Abourizk, 1993)

m) Worker related factors: workforce motivation, unions (Borcherding, 1976; Borcherding and Garner, 1981; CIDC, 1984)

Although a comprehensive list of factors has been identified, data collection efforts on the various factors have not been consistent. Most existing literature focuses on one or two factors and examines those impacts on productivity for a specific discipline. This research, however, considers 18 project environment factors that may influence overall project productivity and assesses a relative degree of impact for each factor. The list of impact factors utilized by this study can be seen in the Section 6.3 of the Alberta benchmarking questionnaire. Consequently, most of the existing research will need to be updated with quantitative and current data from this research to support evaluation of a broader range of impact today.

2.6 LITERATURE REVIEW SUMMARY

A review of the existing literature provides background to support an understanding of Alberta project characteristics, their constraints, and challenges. An overview of the development of benchmarking systems and metrics to measure project performance was also described. Finally, various assessments of the impacts of factors affecting field productivity were outlined.

Although there are some studies focused on the difficulties of managing Alberta projects and their performance problems, prior to this research, no industry standardized system to quantitatively measure project performance tailored to Alberta projects existed. This research captured aspects of project performance such as cost, schedule, changes, engineering and construction productivity, and impact which must be analyzed to identify the root causes behind Alberta projects' poor productivity when compared to typical EMR projects in U.S.

In previous research there has been very little detailed data collected on construction productivity at the discipline levels. Subsequently, the impacts of factors on both the discipline and project productivity are not well understood. It should also be noted that a study with a broader range on the impact of factors with more objective measurement is required to enhance productivity estimates. While it was not possible to obtain measures of every aspect of project performance, this study does provide data necessary to gain new insights to the results of Alberta's heavy industry sector projects.

CHAPTER 3: RESEARCH METHODOLOGY

An overview of the research methodology is summarized in Figure 3.1. The research methodology consists of two main data collection approaches: an Alberta benchmarking system in Section 3.1 and a survey of project practitioners in Section 3.2. The data collected through Alberta benchmarking system were mainly analyzed to establish the three hypotheses of this study, while additional data from the survey of project practitioners were used to validate the second hypothesis of this study. A detailed description of each approach is described in the following sections.

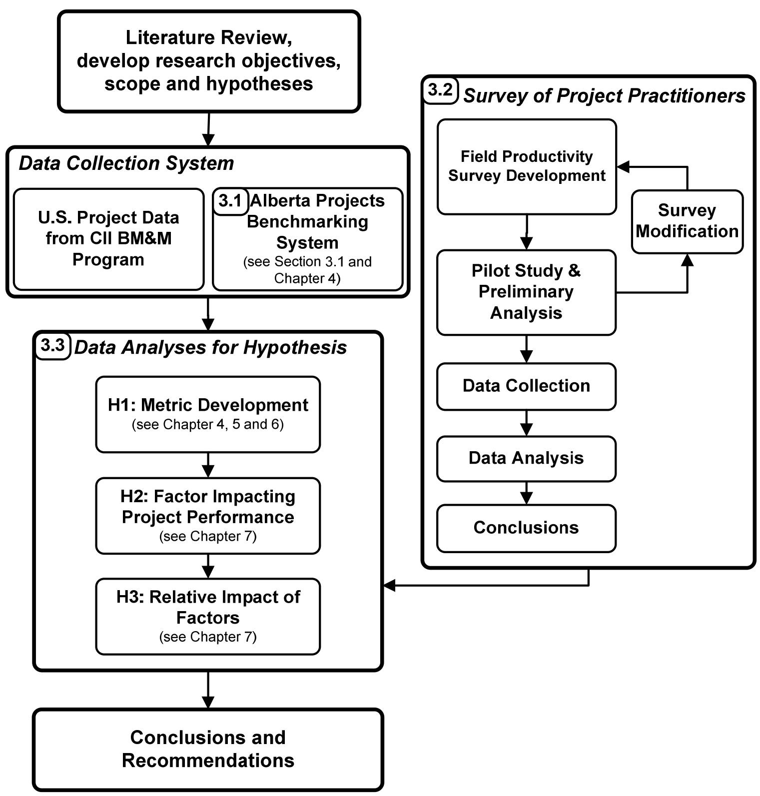

Figure 3.1 Research Methodology

3.1 DEVELOPMENT OF ALBERTA PROJECT BENCHMARKING SYSTEM

The process for the development of the Alberta project benchmarking system is shown in Figure 3.2

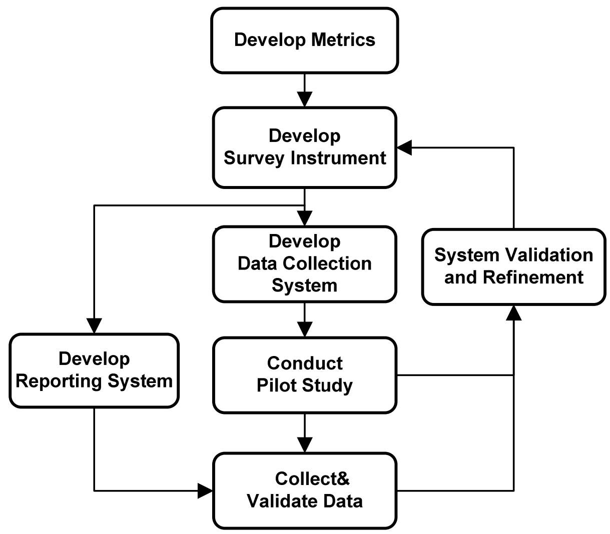

Figure 3.2 Development Process for Alberta Benchmarking System

3.1.1 Development of Metrics Specific to Alberta Challenges

This research primarily addresses project performance, engineering and construction productivity, and metrics to assess best practices developed by the CII BM&M program as discussed in Section 2.2. Many additional metrics to quantify the challenges of working in the Alberta environment were also developed. Metric definitions for this study are provided in Appendix A. The specific metrics utilized in this study were selected and developed through meetings between COAA's benchmarking committee, industry experts and CII's BM&M team, and the list of metrics was refined through several benchmarking workshops and training sessions over three years. The detailed development behind these metrics, their validation and establishment of their values are provided in Chapter 4.

3.1.2 Development of the Survey Instrument

To accommodate the additional metrics required to analyze Alberta projects, the existing CII BM&M Large Project Questionnaire was modified. The Alberta project questionnaire, as provided in Appendix G, was developed through conference calls and face-to-face meetings between the CII BM&M team and the COAA benchmarking committee. Additionally, the questionnaire was refined by feedback and input from 153 industry representatives who attended the COAA benchmarking training program over three years. To better ensure the reliability and consistency of questionnaire responses, all of the questions were reviewed and validated by a survey instrument expert. The questionnaire was developed for both owner and contractor organizations. Each survey provides general project information, budget, schedule, change orders, rework, safety, practice use, engineering and construction productivity, and the impact of factors affecting project performance. Detailed discussion of additional data collection is described in Chapter 4.

3.1.3 Data Collection System

The data collection instrument was developed as a web-based data collection system. This secure system developed by the CII BM&M has matured over the past eight years and is recognized as an efficient and cost-effective tool for companies to benchmark a large number of projects. The online system also supports collaboration of data entry made by multiple project participants. The system was expanded for COAA to allow benchmarking at 2 milestones: project sanction (AFE) and after project completion. Benchmarking at AFE records productivity estimates, while benchmarking after completion provides a comparison of both estimates and actual data.

To facilitate data collection, the online system supports quantity tracking in either Imperial or Metric units. Users can switch the relevant unit of measurement between Imperial (e.g. feet, cubic yard) or Metric (e.g. meter, cubic meter) as needed. As an additional example, conversions of concrete quantities from cubic yards to cubic meters and wire and cable from linear feet to linear meters are achieved by adjusting settings of the online interface. This feature supports projects using hybrid quantity unit systems, which is highly advantageous to large projects managed by multiple companies working in environments that use different units of measure.

A pilot study was initially conducted during the first year of data collection. This pilot study verified the applicability of the system, advantages of project submittal at two milestones, flexibility of hybrid units of measurement, and the consensus of definitions used in the questionnaire. More detail on the data collection system is provided in Chapter 4.

3.1.4 Data Collection and Validation

After project data were submitted online by Alberta industry participants, data were validated for consistency by the author. The author worked with survey participants to ensure the data were as accurate and complete as possible. If an inconsistent response was suspected, or a conflicting response discovered, the author would communicate with the project teams to resolve validation issues and finalize submitted data.

The goal of this validation process was to gather high quality data by eliminating errors and omissions before the project data were entered in the database. In addition, the number of projects submitted by different number of companies was ensured in order to avoid the bias of a disproportionate number of submissions from a single source.

3.1.5 Development of Performance Reporting System

A summary report of individual project metric scores with comparisons to the Alberta database was developed to provide instant online feedback to project teams. The report contains metric scores, database means, performance quartiles, and sample sizes for each metric. The metric comparison report was customized for Alberta projects through a series of discussions, and the method used was refined during meetings with industry representatives. A detailed discussion of the summary report is provided in Chapter 4 and complete documentation is provided in Appendix C.

3.1.6 System Validation and Refinement

After the preliminary data analysis, results were presented to the COAA benchmarking team and industry experts from oil and gas construction companies in Alberta who participate the COAA benchmarking workshops. A validation of the data collection system and a refinement of the questionnaire were done to enhance the effectiveness of the COAA benchmarking system. Validation of the system is essential to ensure that the system is appropriate for the users, flexible for them to enter data, and fully secure for confidentiality. During this time, the metrics, metric framework, definitions of terms and the questionnaire were also validated to find out if anything needed to be refined or added to ensure system creditability and applicability to industry. In conclusion, the COAA benchmarking committee and industry experts who attended workshops, meetings and training sessions over three years of study agreed on the effectiveness of the system. The industry experts reviewed and provided valuable feedback for questionnaire refinement prior to large scale data collection.

3.2 SURVEY OF PROJECT PRACTITIONERS

An additional survey for project practioners was conducted to determine the opinions concerning factors affecting field productivity of construction professionals in Alberta and the U.S. experienced with large EMR projects. The primary purpose is to validate the significant construction productivity factors identified from Alberta benchmarking data. Next, the secondary purpose was to differentiate perceptions between U.S. and Alberta projects for major factors affecting productivity. The survey is provided in Appendix F and a detailed illustration of the survey process is shown in Figure 3.3. A survey was web-based to provide convenience for the respondents and to expedite data collection. An e-mail with the link to the online survey was sent out to industry representatives from CII and COAA companies participating in benchmarking.

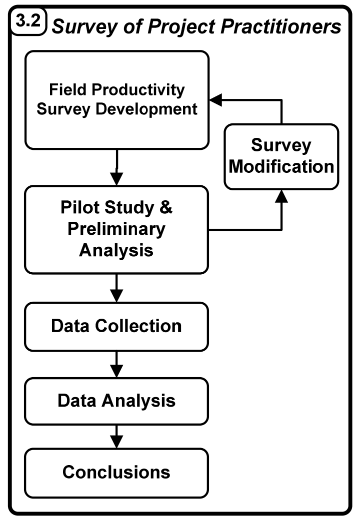

Figure 3.3 Development of Survey of Project Practitioners

The survey consisting of 33 potential factors impacting field productivity as identified from the literature review. The factors were categorized into five major groups: 1) project characteristics, 2) project execution, 3) organization and management strategies, 4) human factors, and 5) other. After an initial pilot study, the survey was modified based on survey results and feedback from experts. The second survey was comprised of the same factors as in the pilot study, but employed a different rating system. The respondents were asked to provide feedback by rating the degree of impact of each factor on a 1 to 10 scale, with 1 signifying minimal impact and 10 denoting substantial impact. The example of the survey is as shown in Figure 3.4. The purpose of this second survey was to obtain a subjective ranking of factors by their average degree of impact.

1. In your experience, please **Rate the Degree** to which each factor listed below **influences or impacts the Field Productivity** of construction projects.

*Scale is 1 to 10. "**1**" refers to **NO** influence or impact. "**10**" refers to **SUBSTANTIAL** impact.*

Example:

Factor	Degree affect to Field Productivity									
	No Impact				Medium Impact					Substantial Impact
1.1 A	1	2	3	4	5	6	7	8	9	10

Project Characteristics Factors	To what degree do these factors influence Field Productivity?									
	No Influence				Medium Influence					Substantial Influence
1.1 Project Size ($)	1	2	3	4	5	6	7	8	9	10
1.2 Project Nature (grassroots, addition etc)	1	2	3	4	5	6	7	8	9	10
1.3 Project Driver (cost, schedule, etc)	1	2	3	4	5	6	7	8	9	10
1.4 Site Location (urban or remote area)	1	2	3	4	5	6	7	8	9	10
1.5 Project Complexity	1	2	3	4	5	6	7	8	9	10
1.6 Contract type (fixed price, cost reimbursable, etc.)	1	2	3	4	5	6	7	8	9	10
1.7 Site Congestion	1	2	3	4	5	6	7	8	9	10

Figure 3.4 Example of Survey of Project Practitioners

This survey of project practitioners serves to augment and strengthen research findings for the third hypothesis of this study. The process of conducting surveys expands the research opportunity to assess a wide range of factors such as management competence and worker attitude. The results of this survey are discussed in Chapter 7.

3.3 DATA ANALYSES FOR HYPOTHESIS TESTING

3.3.1 Statistical Analysis Techniques

Both descriptive and inferential statistical analyses were employed in this study to investigate and establish the three hypotheses described in Chapter 1. The definition of each statistical term and an explanation of each statistical technique are available in Appendix D.

The descriptive statistics describe the data used in the study. There are many kinds of descriptive techniques; however, this study introduces three common methods. Specifically used are the frequency distribution, measurement of central tendency, and measurement of dispersion. By using the frequency distribution, data are analyzed in frequency or percentage and presented in a tabular format, bar chart, pie chart, and histogram. For the measurement of central tendency and dispersion, box and whisker diagrams are utilized to present mean, median and distribution of the data. Figure 3.5 provides an example of a box and whisker plot, including all of the terms.

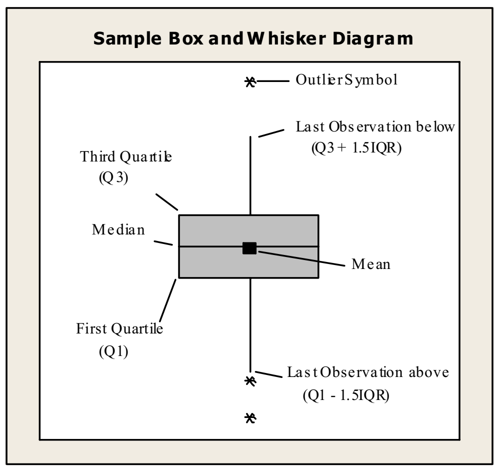

Figure 3.5 Sample Box and Whisker Diagram

The inferential methods are used to extend conclusions beyond descriptive statistics of the data. It is able to infer whether one variable has relationship with another variable and conclude to a broader population. There are various kinds of statistical tests associated to inferential statistical techniques. For comparison purposes, in this study applied box and whisker plots combined with either a standard *t*-test or Analysis of Variance (ANOVA) were utilized to test significance of mean difference between two groups or more (Agresti and Finlay, 1999). Other inferential statistical techniques used in this study are Pearson product moment correlation (r), Spearman (rho) ranking correlation, and simple and multiple linear regression. The test statistics associated to these techniques which are *F*-test, *t*-test and Levene's test were also applied.

3.3.2 Analysis of Hypotheses

The first hypothesis is provided in Figure 3.6. The specific metrics developed for assessing Alberta project performance and productivity are investigated based upon the criteria established in this study. These criteria require both qualitative and quantitative evaluations to confirm the supposition that the metrics are capable of not only assessing and measuring project performance and productivity but also providing meaningful information and norms for comparing projects.

A detailed discussion on the first hypothesis is provided in Chapters 5 and 6. In Chapter 5, descriptive data analysis was applied to generate norms and distribution of new metrics in this study. Also, a qualitative evaluation was performed by validation of the metrics from experts who have extensive experience working on large EMR projects. Again, in Chapter 6, the validity of the metrics is confirmed by presenting the inferential ability with other project performance metrics.

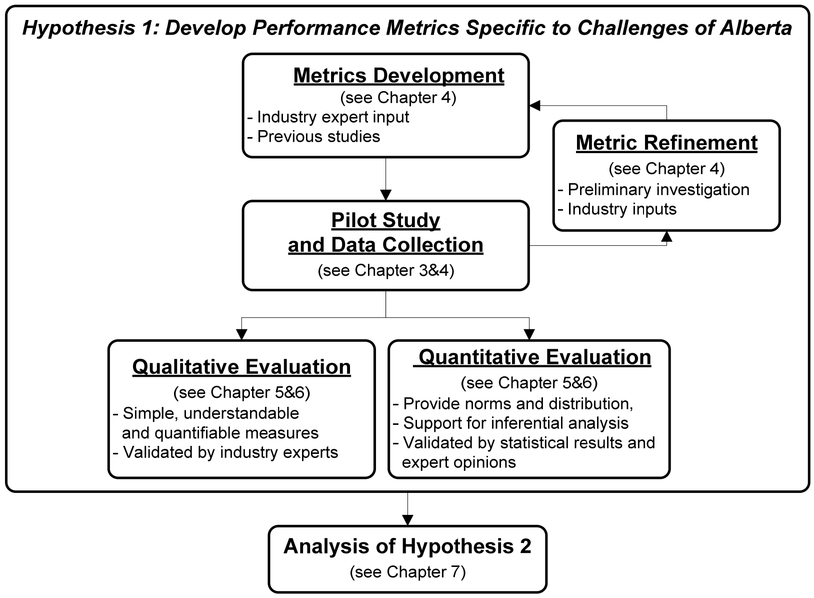

Figure 3.6 Steps for Analysis of Hypothesis 1

Then, the steps for testing hypotheses 2 and 3 are illustrated in Figure 3.7. The second hypothesis is intended to address the theory that factors impacting large EMR project performance and productivity can be identified. The impact of these factors is quantified and correlate to project performance by using Alberta benchmarking data. After major factors impacting project performance and productivity are identified, these factors are validated by the perception of industry experts conducting by additional survey of project practitioners. Lastly, the third hypothesis is to establish the relative impact among factors. Two comprehensive data analysis approaches are purposed in this study to quantify the relative impact of each factor on construction productivity. The detailed investigations of the third hypothesis are presented in Chapters 7.

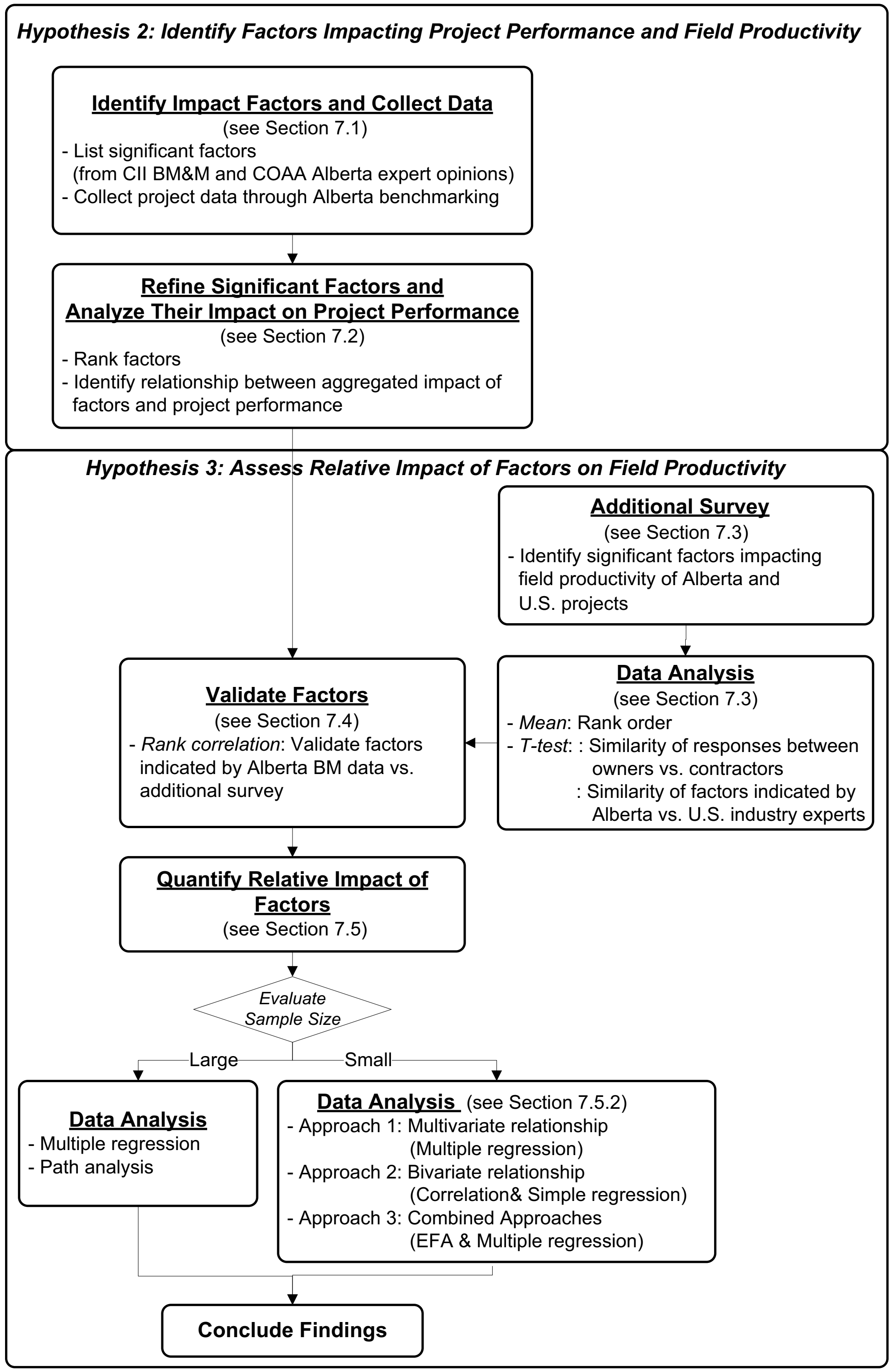

Figure 3.7 Steps for Analysis of Hypothesis 2 and 3

CHAPTER 4: DEVELOPMENT OF THE ALBERTA BENCHMARKING SYSTEM

This study adopted and enhanced the CII BM&M system to address the current need for an industry-wide, standardized benchmarking system specific to the unique characteristics of Alberta major projects. In this chapter, the key details of the development of the Alberta project benchmarking system as shaded boxes shown in Figure 4.1 are described. Development of the additional metrics specific to Alberta challenges, augmentation of data elements in the questionnaire and enhancement of CII's data collection capability are also included. Detailed explanation on metric development confirms the first hypothesis of this study as shown in Figure 4.1. In addition, this chapter explains the development of a comprehensive data reporting system to summarize metric comparisons to meet the research objective.

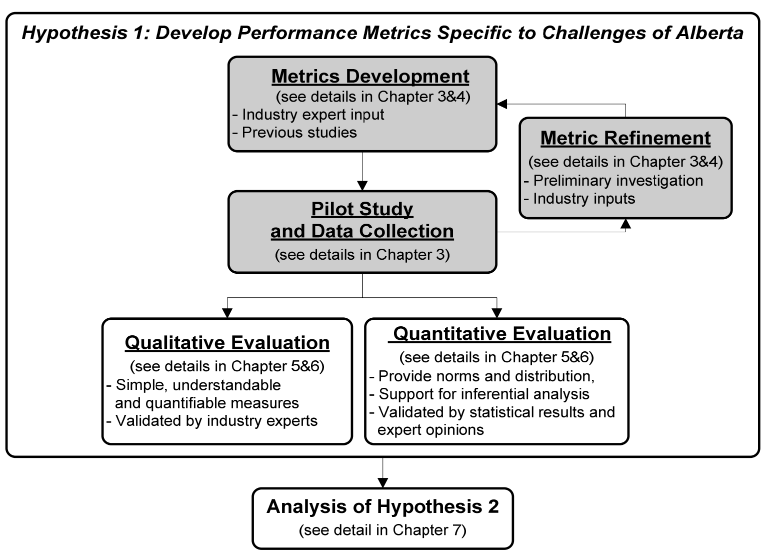

Figure 4.1 Steps for Analysis of Hypothesis 1

4.1 ALBERTA-SPECIFIC METRICS

Alberta specific metrics were incorporated in this study to target the critical issues long suspected to be the root causes behind cost overruns, schedule delays and poor productivity on Alberta projects. A series of COAA benchmarking meetings and conference calls were conducted to identify the key issues specific to the constraints and challenges in Alberta.

The first hypothesis of this study states that metrics for measuring performance specific to constraints in Alberta can be developed and assessed. If this hypothesis is to be established, then these metrics must produce meaningful measures of productivity and project performance and the data for these metrics must be reasonably obtainable through the benchmarking system. The assessment and validation of the new metrics were performed during a span of three years of benchmarking activity. Project metrics and their definitions were refined and validated by the COAA benchmarking committee and 80 industry experts from 19 oil and gas companies in Alberta who attended industry workshops and training seminars.

As shown in Table 4.1, the newly developed metrics are categorized into four main groups designed to measure issues related to project cost, workforce, construction productivity and practices. Detailed discussions of each metric are provided in the following sections.

Table 4.1 Alberta-Specific Metrics

Metrics Related to Project Cost Performance	Direct Construction Cost Factor = $\frac{\text{Total Direct Construction Cost}}{\text{Total Construction Cost}}$
	Indirect Construction Cost Factor = $\frac{\text{Total Indirect Construction Cost}}{\text{Total Construction Cost}}$
	Indirect-Direct Cost Factor = $\frac{\text{Total Indirect Construction Cost}}{\text{Direct Construction Cost}}$
	Major Equipment Cost Factor = $\frac{\text{Total Major Equipment Cost}}{\text{Total Project Cost}}$
	Mechanical & Process Equipment Cost Factor = $\frac{\text{Total Mechanical \& Process Equipment Cost}}{\text{Total Project Cost}}$
Metrics Related to Work force	Indirect-Direct Work Hours Factor = $\frac{\text{Total Indirect Construction Work Hours}}{\text{Total Direct Construction Work Hours}}$
	Offsite Construction Work Hours Factor = $\frac{\text{Offsite Construction Labor Hours}}{\text{Total Construction Labor Hours}}$
	Accuracy of Workforce Predictability = $\frac{\text{Actual Number of Labor at Peak Construction}}{\text{Estimated Number of Labor at Peak Construction}}$
	Percent of Union and Non Union Workers
	Percent of Overtime Work
	Mode of Transportation to Jobsite (%)
	Worker Accommodations (%)
Metrics Related to Construction Productivity	Non Metallic Piping Productivity
	Heat Tracing Tubing Productivity
	Percent Material and Equipment Procured by Owner
	Transmission Line Productivity
	Total Installed Unit Cost ($/ Installed Quantity)
	Module Installation Onsite Productivity = $\frac{\text{Total Labor Work Hours to Install Module Onsite}}{\text{Installed Quantity}}$
	Scaffolding Productivity = $\frac{\text{Total Scaffolding Work Hours}}{\text{Total Direct Construction Work Hours}}$
	Scaffolding Cost Factor = $\frac{\text{Total Installed Scaffolding Cost}}{\text{Total Direct Construction Cost}}$
	Estimating Accuracy of Productivity = $\frac{\text{Actual Direct Labor Productivity (WH/Installed Quantity)}}{\text{Estimated Direct Labor Productivity (WH/Installed Quantity)}}$
	Estimating Accuracy of Total Installed Unit Cost (TIUC) = $\frac{\text{Actual TIUC (\$/Installed Quantity)}}{\text{Estimated TIUC (\$/Installed Quantity)}}$

4.1.1 Metrics Related to Cost

4.1.1.1 Indirect and Direct Construction Cost

According to the COAA benchmarking committee and previous studies, the indirect construction cost for Alberta projects tends to be significantly greater than for similar projects in other locations. Indirect costs are accrued for transporting workers to the jobsite by bus or plane and also for building work camps. Most Alberta Oil Sands projects are in remote locations, which subsequently require additional services. Indirect costs include access roads, taxiways for airplanes to land, as well as the construction of thousand unit work camps and cold weather facilities to protect against the extreme environment, which afflicts Alberta four to five months of the year. During the winter, the lowest temperatures are typically around -40 degrees Celsius. To capture the impacts of these indirect costs, metrics were developed as follows:

$$Indirect\ Construction\ Cost\ Factor = \frac{Total\ Indirect\ Construction\ Cost}{Total\ Project\ Cost}$$

$$Indirect - Direct\ Cost\ Factor = \frac{Total\ Indirect\ Construction\ Cost}{Direct\ Construction\ Cost}$$

Indirect construction cost factor is a ratio of indirect construction cost divided by the total project cost, while indirect-direct cost factor is a ratio of indirect construction cost divided by the direct construction cost. These two metrics were defined to yield the percentage of money spent on indirect work. By quantifying the proportion of work performed on indirect tasks, their impacts on overall performance can be assessed. Associated with these metrics quantifications, a consensus definition of costs to be included and excluded in direct and indirect accounts were also defined by the COAA and CII benchmarking teams.

In this study, direct costs were defined as costs of work which are readily or directly attributed to, or become an identifiable part of, the final project (e.g., piping labor and material), while indirect costs are those that cannot be attributed readily to a part of the final product (e.g. cost of managing the project). Direct and Indirect accounts are as shown in Table 4.2. Early in the study, there were some discrepancies on tracking direct and indirect cost between owner and contractor organizations. Owners reported that they usually categorize construction equipment as an indirect construction cost, and labor burdens and fringe benefits as direct; however, some contractors tended to do vice versa. Later, the definitions were revised with agreement on reporting requirements both owners and contractors by 80 industry experts from 19 participating companies.

Table 4.2 Definitions for Direct and Indirect Construction Costs

Construction Direct and Indirect Cost

Direct costs are those which are readily or directly attributed to, or become an identifiable part of, the final project (e.g., piping labour and material). Indirect costs are costs that cannot be attributed readily to a part of the final product (e.g. temporary facilities).

Please use the following table as a guide in categorizing direct and indirect construction cost.

Direct Construction Cost	Indirect Construction Cost
Direct labor - See construction productivity table (questionnaire p.27)	Indirect labor - See construction productivity table
Labour burdens and fringe benefits	Overtime premium (additional cost for which no work is performed)
Direct subcontracts	Mobilization, Demobilization
Bulk materials - See bulk material table (questionnaire p.12)	Construction office trailers and equipment.
	Construction utilities (power, water etc.)
	Temporary construction (e.g. roads, fencing, fab. shops, etc.)
	Construction equipment (rental/ ownership& consumerables – fuel, oil, etc.)
	Other consumables- small tools, supplies
	Scaffolding materials (rental/ ownership)
	Field services
	Permits (construction related)
	Vendor representatives
	Freight (for items listed in this table)
	Catering, accommodations
	Travel
	Misc. (insurance, etc.)
	Indirect subcontracts

Note: For benchmarking purposes exclude the following:

- Demolition cost
- Remediation cost
- Site preparation cost (construction cost begins with excavation for foundations or driving of piles)

Provide data for Construction subtotal if indirect and indirect breakout is not available.

4.1.1.2 Cost of Major Equipment

Two metrics for equipment were developed as a ratio of the total purchase cost of major equipment and also the total purchase cost of only the mechanical and process equipment, both divided by total project cost, as follows:

$$Major\ Equipment\ Cost\ Factor = \frac{Total\ Major\ Equipment\ Cost}{Total\ Project\ Cost}$$

$$Mechanical\ \ \&Process\ Equipment\ Cost\ Factor = \frac{Total\ Mechnical\ \&\ Process\ Equipment\ Cost}{Total\ Project\ Cost}$$

The costs of major and mechanical equipment for Alberta Projects can be substantial because it includes not only the cost of process and mechanical equipment but also mining equipment and construction equipment left onsite and used after commissioning such as loaders and haulers, excavators and material handling equipment. Costs can total up to hundreds million dollars. The purpose of these metrics is to determine the extent to which the overall project cost performance is driven by the cost of equipment. In some cases, the cost of major equipment is double from the initial estimate due to either cost escalation or changes which could influence the overall project cost to be significantly overrun.

Table 4.3 provides the equipment reference table developed by the COAA and CII BM&M team. The list for major equipment developed by CII BM&M was appended to accommodate mining equipment and mechanical and process equipment. Mining equipment includes equipment used for and be a part of oil sands mining process such as loaders and haulers and excavators. Mechanical and process equipment includes material handling equipment such as conveyors, and special processing equipment such as crushers and separators used for oil sands extraction.

Table 4.3 Definitions for Major Equipment, Mechanical and Process Equipment Costs

Total Cost of Major Equipment

The purpose of this question is to determine the extent to which the overall project cost is driven by the purchase of **major equipment in general and more particularly, mechanical and process equipment.** Please see the Equipment Reference Table provided below. Record the total purchase cost of major equipment overall as well as the total purchase cost of mechanical and process equipment.

Total Cost of Major Equipment $____________________ ◘ N/A ◘ Unknown

Total Cost of Mechanical and Process Equipment $___________ ◘ N/A ◘ Unknown

Equipment Reference Table	
Examples of Major Equipment	**Kinds of Equipment Covered**
Electrical Equipment	
HVAC Systems	Prefabricated air supply houses
Motors	600V and above
Electricity Generation and Transmission	Major electrical items (e.g., unit substations, transformers, switch gear, motor-control centers, batteries, battery chargers, turbines and other miscellaneous power generation equipment).
Mining Equipment	
Loaders and Haulers	Dozers, haul trucks, graders.
Excavators	Hydraulic/ electric shovels, draglines, etc.
Material Handling Equipment	
Mechanical & Process Equipment	
Exchangers	Heat transfer equipment: tubular exchangers, condensers, evaporators, reboilers, coolers (including fin-fan coolers and cooling towers).
Pumps	All types of liquid pumps and drivers.
Direct-fired Equipment	Fired heaters, furnaces, boilers, kilns, and dryers, including associated equipment such as super-heaters, air preheaters, burners, stacks, flues, draft fans and drivers, etc.
Columns and Pressure Vessels	Towers, columns, reactors, unfired pressure vessels, bulk storage spheres, and unfired kilns; includes internals such as trays and packing.
Tanks	Atmospheric storage tanks, bins, hoppers, and silos.
Vacuum Equipment	Mechanical vacuum pumps, ejectors, and other vacuum producing apparatus and integral auxiliary equipment.
Material Handling Equipment	Conveyers, cranes, hoists, chutes, feeders, scales and other weighing devices, packaging machines, and lift trucks.
Package Units	Integrated systems bought as a package (e.g., air dryers, air compressors, refrigeration systems, ion exchange systems, etc.).
Special Processing Equipment	Agitators, crushers, pulverizers, blenders, separators, cyclones, filters, centrifuges, mixers, dryers, extruders, fermenters, reactors, pulp and paper, and other such machinery with their drivers.
Include freight. Exclude costs of project team, costs for field services, bulk construction equipment (such as valves, bus duct etc.) and off-the-shelf equipment.	

4.1.2 Metrics Related to Workforce

A second group of new metrics were developed to study workforce issues unique to Alberta projects. These metrics were designed to measure indirect construction work hours, the percentage of offsite construction work, peak construction workforce, mode of travel to the worksite and accommodation of workers.

4.1.2.1 Indirect and Direct Construction Work Hours

Although indirect cost metrics can reveal the influence of material, equipment and labor, it cannot determine how productively the labor work hours contributed to the final product. In some cases, supporting work hours are significantly high and not in proportion to direct work, indicating inefficiency, and therefore problems in project productivity. To measure this, a ratio of indirect work hours divided by direct work hours is collected.

$$Indirect - Direct\ Construction\ Work\ Hours\ Factor = \frac{Total\ Indirect\ Construction\ Work\ Hours}{Total\ Direct\ Construction\ Work\ Hours}$$

A value greater than 1 indicates the more hours are spent on works that do not directly contribute to the final product. The section of the questionnaire is presented in Figure 4.2. Estimated and actual direct and indirect construction work hours are captured, as well as the ratio of these two in case only the ratio is available.

Construction Work hours	Estimated		Actual	
	Total Work hours	Total Indirect WH/ Total Direct WH	Total Work hours	Total Indirect WH/ Total Direct WH
Direct				
Indirect				

Figure 4.2 Data Collection of Direct and Indirect Construction Work Hours

4.1.2.2 Percentage of Offsite Construction Work Hours

Offsite fabrication is considered to be a strategic project execution approach for Alberta projects. Because most large EMR projects in Alberta are schedule-driven and are burdened by severe weather, labor shortages and a remote location, Alberta projects commonly use a high level of offsite construction. Although in some cases, offsite construction may lead to increased cost, it is still viable because it offers a substantial opportunity to improve project schedule performance. As a result, this study captures the percentage of offsite construction labor as shown below:

$$\textit{Offsite Construction Work Hours Factor} = \frac{\textit{Total Offsite Construction Labor Hours}}{\textit{Total Construction Labor Hours}}$$

The metric was developed as a ratio of the offsite construction labor hours of all modules divided by the total construction labor hours. It measures offsite labor hours for building modules, and enables the analysis of the advantages of having modules preassembled rather than installed piece by piece onsite. Data are reported to the nearest 10%, as shown in Figure 4.3.

d. Percent Offsite Construction Labor Hours

Choose a percentage value that best describes the level of offsite labour hours for building modules. This value should be determined as a ratio of the offsite labour hours of all modules divided by **<u>total construction hours</u>**.

◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**

Figure 4.3 Data Collection and Definitions for Construction Work Hours

4.1.2.3 Percent of Overtime Work

Overtime work is common in Alberta EMR projects because these projects required a lot more time than typical projects to wrap up after daily work. This includes material handling, cleaning equipment and tools, and extra work to due to severe weather. As indicated by the COAA BM committee, the level of overtime is one of the major strategies for a project management team to consider in order meeting planned productivity. Nonetheless, a research study done by Dozzi and Abourizk (2003) indicated that working more than 40 hours a week reduces productivity. It is still questionable whether having more overtime on a 40 hour work week is more productive than having it on a 50 hour work week. As a result, a metric to measure overtime work as a percentage of total field work hours was developed in this study to allow quantitative assessment on the advantage of different work schedules. The questions used for method of collecting these data are shown in Figure 4.4.

Level of Overtime as % of total field Work hours

Indicate below the planned and actual percentage of field work hours classified as overtime.

Planned overtime	Actual overtime
_______________% ◘ Unknown	_______________% ◘ Unknown

If the ratio of Actual exceeds Planned overtime, please provide the reason why:

____

Figure 4.4 Data Collection for Overtime Metric

4.1.2.4 Workforce Predictability

In general, mega projects require a large workforce. It is critical that construction project managers sufficiently estimate the number of laborers necessary during the peak of construction, as an insufficient workforce greatly impacts the schedule and project cost. Thus, the data shown in Figure 4.5 were developed to produce a metric to capture the accuracy of the estimated workforce required at peak project execution. The metric is a ratio of actual divided by the planned peak workforce. It should be noted that the estimate of peak workforce depends a great deal on the accuracy of the productivity rate used.

$$Accuracy\ of\ Workforce\ Predictability = \frac{Actual\ Number\ of\ Labor\ at\ Peak\ Construction}{Estimated\ Number\ of\ Labor\ at\ Peak\ Construction}$$

Peak construction work force

Indicate the peak construction work force planned and achieved for this project by inputting the maximum number of working personnel at the jobsite at one time:

Planned Peak Work Force	Actual Peak Work Force
_______________ ◘ Unknown	_______________ ◘ Unknown

Figure 4.5 Data Collection of Peak Construction Work Force

4.1.3 Construction Productivity Metrics

As mention earlier, this study applied CII construction productivity metrics which measured productivity in terms of work hours per installed quantity. Table 4.4 presents the construction productivity metrics which are organized into seven discipline categories defined by the original CII CPMS, as documented by Park (2002). The COAA committee requested that metrics for large EMR projects added to the seven categories, as depicted in red text in Table 4.4. The examples are such as non metallic piping, heat tracing tubing, transmission line (high voltage), module installation and scaffolding.

Table 4.4 Construction Productivity Metric Categories

Concrete
- **Total Concrete**
  - **Slabs** (CM)
    - On-Grade (CM)
    - Elevated Slabs/On Deck (CM)
    - Area Paving (CM)
  - **Foundations** (CM)
    - < 4 CM
    - 4 – 15 CM
    - 15 –38 CM
    - ≥ 38 CM
  - **Concrete Structures** (CM)

Structural Steel
- **Total Steel** (MT)
  - Structural Steel (MT)
  - Pipe Racks & Utility Bridges (MT)
  - Miscellaneous Steel (MT)

Instrumentation
- **Loops** (Count)
- **Devices** (Count)

Piping
- **Small Bore (2-1/2" & Smaller)** (LM)
  - Carbon Steel (LM)
  - Stainless Steel (LM)
  - Chrome (LM)
  - Other Alloys (LM)
  - Non Metallic (LM)
- **Inside Battery Limits (ISBL)** (LM) **Large Bore (3" & Larger)** (LM)
  - Carbon Steel (LM)
  - Stainless Steel (LM)
  - Chrome (LM)
  - Other Alloys (LM)
  - Non Metallic (LM)
- **Outside Battery Limits (OSBL)** (LM) **Large Bore (3" & Larger)** (LM)
  - Carbon Steel (LM)
  - Stainless Steel (LM)
  - Chrome (LM)
  - Other Alloys (LM)
  - Non Metallic (LM)
- **Heat Tracing Tubing (LM)**

Electrical
- **Total Electrical Equipment** (Each)
  - Panels and Small Devices (Each)
  - Electrical Equipment below 1kV (Each)
  - Electrical Equipment over 1kV (Each)
- **Conduit** (LM)
  - Exposed or Above Ground Conduit (LM)
  - Underground, Duct Bank or Embedded Conduit (LM)
- **Cable Tray** (LM)
- **Wire and Cable** (LM)
  - Control Cable (LM)
  - Power and Control Cable below 1kV (LM)
  - Power Cable above 1kV (LM)
- **Transmission Line** (LM)
  - High Voltage above 25kV (LM)
- **Other Electrical Metrics**
  - Lighting (Each)
  - Grounding (LM)
  - Electrical Heat Tracing (LM)

Equipment
- **Pressure Vessels (Field Fab.& Erected)** (Each), (MT)
- **Atmospheric Tanks (Shop Fabricated)** (Each), (MT)
- **Atmospheric Tanks (Field Fabricated)** (Each), (MT)
- **Heat Transfer Equipment** (Each), (MT)
- **Boiler & Fired Heaters** (Each), (MT)
- **Rotating Equipment** (Each), (HP)
- **Material Handling Equipment** (Each), (MT)
- **Power Generation Equipment** (Each), (kW)
- **Other Process Equipment** (Each), (MT)
- **Modules & Pre-assembled Skids** (Each), (MT)

Insulation
- **Insulation Equipment** (SM)
- **Insulation Piping** (ELM)

Module Installation
- **Pipe Racks** (MT)
- **Process Equipment Modules** (MT)
- **Building** (SM)

Scaffolding
- **Scaffolding Work Hours Factor**
- **Scaffolding Cost Factor**

$$\text{Construction Productivity} = \frac{\text{Total Direct Installed Work Hours}}{\text{Total Installed Quantity}}$$

4.1.3.1 Module Installation Productivity Metric

As specified by the COAA BM committee, module installation is sub-categorized into pipe racks, process equipment, and building. These are major components, usually prefabricated in factories or other more workable environments. The definition for the three modules is provided in the Alberta benchmarking questionnaire. For example, pipe rack module structure has several components such as steel framework, walkway, platform to support piping, electrical tray and insulation. These are preassembled in the module before it is transported to the final destination. The productivity metrics are intended to measure labor productivity to install pipe rack, process equipment and building modules onsite. Labor productivity of pipe rack modules are measured in installed work hours per metric ton, while building modules are measured in installed work hours per square meter. Thus, data shown in Figure 4.6 were developed to produce a metric to capture work hours and associated installed quantity.

$$\textit{Module Installation Productivity} = \frac{\textit{Total Labor Onsite Work Hours to Install Modules}}{\textit{Total Quantity of Modules}}$$

<table>
<tr><th rowspan="3">Pipe Racks Modules</th><th colspan="4">Estimated Productivity</th></tr>
<tr><th>None</th><th>Quantity (MT)</th><th>WH</th><th>Total Installed Unit Cost ($/ MT)</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Pipe rack module structure may include several components such as structural steel for framework, walkway, platform to support the piping, piping c/w (cooling water) valving. It also may include electrical tray, heat tracing and insulation.</td></tr>
</table>

<table>
<tr><th rowspan="3">Process Equipment Modules</th><th colspan="4">Estimated Productivity</th></tr>
<tr><th>None</th><th>Quantity (MT)</th><th>WH</th><th>Total Installed Unit Cost ($/ MT)</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

Building Modules	Estimated Productivity			
	None	Quantity (SM)	WH	Total Installed Unit Cost ($/ SM)
Building Modules are considered as 1 (or more) structural framework structures with a portion (or all of the structure) attached with a building cladding. The structures must be suitable for transport, and fabricated in a location remote to the final location. Examples of modules with buildings are: Electrical MCC buildings, Piping Manifold Buildings, etc.				

Figure 4.6 Data Collection for Module Installation

4.1.3.2 Scaffolding Productivity Metrics

Scaffolding is a crucial and costly component of construction on Alberta projects. The analysis of scaffolding cost influences the decision whether to rent or purchase scaffolding at the start of the project. Rental costs can triple if there is an extension in construction duration, leaving the scaffolding standing longer than anticipated. As a result, questions regarding the procurement of scaffolding material (owner provided, contractor rented, or contractor purchased) were added to the questionnaire as shown in Figure 4.7. Then, the total installed scaffolding cost, which includes direct labor, materials and equipment costs were collected. Likewise, a metric measuring the total work hours required for scaffolding installation divided by total direct hours was developed to determine the portion of labor contributing to the cost on scaffolding and to evaluate the efficiency in work sequence planning.

$$Scaffolding\ Productivity\ Rate = \frac{Scaffolding\ Work\ Hours}{Total\ Direct\ Construction\ Work\ Hours}$$

$$Scaffolding\ Cost\ Factor = \frac{Total\ Installed\ Scaffolding\ Cost}{Total\ Direct\ Construction\ Cost}$$

Scaffolding	Actual				
	None	Sub contracted (Yes or No)	Total Scaffolding Work- Hours	Scaffolding WH/ Total direct hours	Total Installed Scaffolding Cost ($)

Scaffold Materials

- Free Issue to Contractor
- Rented
- Purchased & Included as part of Scaffold Cost

Figure 4.7 Data Collection for Scaffolding Productivity Metrics

4.1.4 Estimating Accuracy Metrics

Productivity and the estimated installed unit cost are critical for projects burdened by challenging factors like those of Alberta. Some projects have been underestimated by 100%, therefore highlighting the need for a skill set of people and project teams to adjust productivity estimates and costs according to the extent conditions. Underestimated productivity and installed unit costs can drive additional project cost significantly due to their unplanned nature. Therefore, two set of metrics which are unit less were created in this study, one to determine the accuracy of the estimated productivity rate and the other for estimated Total Installed Unit Cost (TIUC).

$$Estimating\ Accuracy\ of\ Productivity\ Rate = \frac{Actual\ Labor\ Productivity\ (WH\ /\ Installed\ Quantity)}{Estimated\ Labor\ Productivity\ (WH\ /\ Installed\ Quantity)}$$

$$Estimating\ Accuracy\ of\ TIUC = \frac{Actual\ TIUC\ (\$\ /\ Installed\ Quantity)}{Estimated\ TIUC\ (\$\ /\ Installed\ Quantity)}$$

The accuracy metrics are measured in actual values divided by estimated values, and were applied to each element tracked in the study's construction productivity section. The purpose of these metrics is to determine how the estimated productivity rate and TIUC deviate from the actual results. A value of estimating accuracy metric greater than 1 indicates underestimated productivity and unit cost overrun from estimates. Both actual and estimated productivity and TIUC data were collected in every major construction category as shown in Figure 4.8.

Slabs	**Estimated Productivity**			
	None	**Quantity (CM)**	**WH**	**Total Installed Unit Cost ($/CM)**
On-Grade				
Elevated Slabs /On Deck				
Area Paving				
Total Slabs				
Total Installed Unit Cost (TIUC) for Total Slabs is the weighted average by quantity of the On-Grade, Elevated Slabs/ On Deck, Area Paving and any other slabs not included above.				

Slabs	**Actual Productivity**				
	None	**Sub contracted (Yes or No)**	**Installed Quantity (CM)**	**Actual WH (including rework) (hours)**	**Total Installed Unit Cost ($/CM)**
On-Grade					
Elevated Slabs /On Deck					
Area Paving					
Total Slabs					
Total Installed Unit Cost (TIUC) for Total Slabs is the weighted average by quantity of the On-Grade, Elevated Slabs/ On Deck, Area Paving and any other slabs not included above.					

Figure 4.8 Example of Data Collected for Estimated and Actual Productivity and TIUC

4.1.5 Best Practices

The level of implementation of 14 best practices was also measured in this study in order to investigate current used management practices. Analysis will provide the basis for making recommendations on how to improve project performance in Alberta. Thirteen best practices were adopted from CII. They are comprised of management practices which have been proven to help improve project outcomes by CII members for many years. The list of these best practices and their definitions as defined by CII, are shown as follows:

1) Front End Planning – is the essential process of developing sufficient strategic information with which owners can address risk and make decisions to commit resources in order to maximize the potential for a successful project.

2) Project Risk Assessment – Project risk assessment is the process to identify, assess and manage risk. The project team evaluates risk exposure for potential project impact to provide focus for mitigation strategies.

3) Team Building – is a project-focused process that builds and develops shared goals, interdependence, trust and commitment, and accountability among team members and that seeks to improve team members' problem- solving skills.

4) Alignment during Front End Planning – is the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniform, defined and understood set of project objectives.

5) Constructability – is the effective and timely integration of construction knowledge into the conceptual planning, design, construction, and field operations of a project to achieve the overall project objectives.

6) Design for Maintainability – is the optimum use of facility maintenance knowledge and experience in the design/engineering of a facility to pertain the ease, accuracy, safety and economy in the performance of lifecycle maintenance.

7) Material Management – is the planning, controlling, and integrating of the materials takeoff, purchasing, economic, expediting, transportation, warehousing, and issue functions in order to achieve a smooth, timely, efficient flow of materials to the project in the required quantity, the required time, and at an acceptable price and quality.

8) Project Change Management – is the process of incorporating a balanced change culture of recognition, planning, and evaluation of project changes in an organization to effectively manage project changes.

9) Zero Accident Techniques – include the site-specific safety programs and implementation, auditing, and incentive efforts to create a project environment that embraces the mind set that all accidents are preventable and that zero accidents is an obtainable goal.

10) Quality Management – incorporates all activities conducted to improve the efficiency, contract compliance and cost effectiveness of design, engineering, procurement, QA/QC, construction and startup elements of construction projects.

11) Automation/Integration (AI) Technology – addresses the degree of automation and level of use and integration of automated systems for predefined tasks/work functions common to most projects.

12) Prefabrication/ Preassembly/ Modularization (PPMOF) – is defined as several manufacturing and installation techniques, which move many fabrication and installation activities from the plant site into a safer and more efficient environment.

13) Planning for Startup – is the effectiveness of planning on startup activities that facilitate the implementation of the transitional phase between plant construction completion and commercial operations, including all of the activities bridging these two phases.

An additional fourteenth practice, Workface Planning (WFP), developed specifically for Alberta projects, was surveyed in this study. WFP is defined by COAA as the process of organizing and delivering all elements necessary, before work is started, to enable craft persons to perform quality work in a safe, effective and efficient manner. The main propose of WFP is to improve onsite productivity by having the right things at the right place at the right time (COAA). However, as decided by the COAA BM committee, only key questions were selected from the full version of the Workface Planning Best Practice. The algorithm to calculate the metric score was also adapted from its original 0 to 150 scale to 0 to 10 scale in order to be consistent with CII best practices score. As shown in Figure 4.9, the questionnaire is composed of eight questions, which were divided into four critical areas: 1) field installation work package (FIWP), 2) planners, 3) engineering and construction work package release plan and approvals, and 4) integration and coordination of FIWP. Project teams were asked to assess how intensively they performed on each activity and a Likert scale is used to rate the responses. The weight for each question was assigned by the COAA BM committee, to calculate the underlying score (WFP score). Figure 4.9 illustrates how the weights were assigned to each response in order to produce the WFP score.

Critical Areas		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	NA / UNK
A. Field Installation Work Packages (FIWP)							
A.1	Work is always packaged in Field Installation Work Packages (FIWP). ***(25% of WFP Score)*** *Clarification: An FIWP is a detailed scope of the work to be completed by a crew, over a specified period of time (usually a 1 to 4 week period).*	◘ ***0***	◘ ***0.625***	◘ ***1.25***	◘ ***1.875***	◘ ***2.50***	◘
A.2	Dedicated Planner completes FIWP and signs-off as ready before FIWP is released to crew. ***(25% of WFP Score)*** *Clarification: An FIWP Checklist is discipline specific (civil, structural, piping, electrical, etc.) and itemizes all the information and documentation that should be part of the completed FIWP.*	◘ ***0***	◘ ***0.625***	◘ ***1.25***	◘ ***1.875***	◘ ***2.50***	◘
B. Planners							
B.1	Dedicated planner(s) develop the Field Installation Work Packages (FIWP)? ***(15% of WFP Score)*** *Clarification: A dedicated planner spends virtually all of their time developing FIWP.*	◘ ***0***	◘ ***0.375***	◘ ***0.75***	◘ ***1.125***	◘ ***1.50***	◘
C. EWP/CWP Release Plan and Approvals							
C.1	Engineering Work Package (EWP) identification and release plans are developed prior to the start of detailed engineering, which are reviewed and agreed to by the contractor or construction management. ***(7% of WFP Score)***	◘ ***0***	◘ ***0.175***	◘ ***0.35***	◘ ***0.525***	◘ ***0.7***	◘
C.2	Construction Work Package (EWP) identification and release plans are developed prior to the start of detailed engineering, which are reviewed and agreed to by engineering. ***(7% of WFP Score)***	◘ ***0***	◘ ***0.175***	◘ ***0.35***	◘ ***0.525***	◘ ***0.7***	◘
D. Integration and Coordination of FIWP							
D.1	Responsibility for integration planning was established to proactively resolve anticipated conflicts between individual FIWP's. ***(7% of WFP Score)***	◘ ***0***	◘ ***0.175***	◘ ***0.35***	◘ ***0.525***	◘ ***0.7***	◘
D.2	Responsibility for material coordination of individual FIWP's were assigned to a dedicated Coordinator(s). ***(7% of WFP Score)***	◘ ***0***	◘ ***0.175***	◘ ***0.35***	◘ ***0.525***	◘ ***0.7***	◘
D.3	Responsibility for specialty tools and construction equipment coordination for each FIWP was assigned to a dedicated Coordinator(s). ***(7% of WFP Score)***	◘ ***0***	◘ ***0.175***	◘ ***0.35***	◘ ***0.525***	◘ ***0.7***	◘

Figure 4.9 Data Collection and Scoring Value for Work Force Planning Metric

4.2 QUESTIONNAIRE FOR ALBERTA CHALLENGES

The development of questions tailored to the challenges of the Alberta environment was one of the major milestones in this research. During the first two years of this research effort, the questionnaire development included reviewing and modifying CII's large project questionnaire version 9 and adding new questions. The COAA benchmarking committee and the CII BM&M team (including the author) had monthly conference calls to discuss and identify the critical information needed to be captured through the survey instrument. Some definitions were merely revised to conform to the Alberta environment and terminology, while a large number of questions were newly defined. The additional questions were mostly related to project description, work force characteristics, and construction productivity.

For example, in the project description section of the survey was expanded to include oil sands mining/ extraction, oil sands SAGD, oil sands upgrading, and cogeneration as shown in red text in Figure 4.10. Also, questions identifying whether the project is part of a larger project, the percent of offsite construction labor to total construction hours, and union to non union workforce by discipline were added as shown in Figures 4.11, 4.12 and 4.13.

Principle Type of Project:

Choose a Project Type which **best** describes the project from the categories below. If the project is a mixture of two or more of those listed, select the principle type. If the project type does not appear in the list, select other under the appropriate industry group and specify the project type.

Heavy Industrial

- ☐ Chemical Manufacturing
- ☐ Electrical (Generating)
- ☐ Environmental
- ☐ Metals Refining/Processing
- ☐ Mining
- ☐ Natural Gas Processing
- ☐ Oil Exploration/Production
- ☐ Oil Refining
- ☐ Oil Sands Mining/Extraction
- ☐ Oil Sands SAGD
- ☐ Oil Sands Upgrading
- ☐ Cogeneration
- ☐ Pulp and Paper
- ☐ Pipeline
- ☐ Gas Distribution
- ☐ Other Heavy Industrial

Light Industrial

- ☐ Automotive Manufacturing
- ☐ Consumer Products Manufacturing
- ☐ Foods
- ☐ Microelectronics Manufacturing
- ☐ Office Products Manufacturing
- ☐ Pharmaceutical Manufacturing
- ☐ Pharmaceutical Labs
- ☐ Clean Room (Hi-Tech)
- ☐ Other Light Industrial

Figure 4.10 Additional Project Type

1.1 Project Nature

From the list below select the category that best describes the nature of this project. If your project is a combination of these natures, select the category that you would like your project to be benchmarked against. Please see the glossary for definitions.

The Project Nature was:

- ☐ Grass Roots, Green Field
- ☐ Modernization, Renovation
- ☐ Addition, Expansion
- ☐ Other Project Nature (Please describe):

Is this project part of a larger project? ◘ **Yes** ◘ **No**

If Yes, please describe: ______________________________

Figure 4.11 Additional Question on Project Nature

d. Percent Offsite Construction Labor Hours

Choose a percentage value that best describes the level of offsite labor hours for building modules. This value should be determined as a ratio of the offsite labor hours of all modules divided by **total construction hours**.

◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**

Figure 4.12 Additional Question for Offsite Construction Metric

1.9 Percentage Union Workforce

Please indicate the percentage of Building Trades, Alternate Union and Non Union Labor employed for the following disciplines. Each row should sum up to 100%.

Building Trades Unions are organizations of workers formed for the purpose of advancing their members' interests in respect to wages, benefits and working conditions. Building trades unions typically represent single trades.
Example: IBEW - International Brotherhood of Electrical Workers

Alternate Unions are multicraft unions or wall-to-wall unions similar in purpose to building trades unions but are inclusive of multiple trades and industries.
Example: CLAC - Christian Labor Association of Canada

Discipline	Percentage Building Trades	Percentage Alternate Union	Percentage Non Union	Total (%)
Concrete	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Structural Steel	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Electrical	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Piping	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Instrumentation	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Equipment	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Insulation	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%

Figure 4.13 Additional Question for Union Workforce Metric

The largest addition to the Alberta benchmarking questionnaire is estimated quantity and work hours in all construction productivity work disciplines. Also, two sections for module installation, scaffolding cost and work hours, and construction indirect and direct work hours were added, as illustrated in Figures 4.14, and 4.15. Moreover, sections for work schedules, worker accommodations, mode of travel to the jobsite, winter work, and Canadian safety metrics according to local industry guidelines (WCB and CAPP) were added as shown in Figure 4.16. All additional questions for Alberta projects are provided in Appendix G delineated in red text.

Pipe Racks Modules	Estimated Productivity			
	None	Quantity (MT)	WH	Total Installed Unit Cost ($/ MT)

Pipe rack module structure may include several components such as structural steel for framework, walkway, platform to support the piping, piping c/w (cooling water) valving. It also may include electrical tray, heat tracing and insulation.

Pipe Racks Modules	Actual Productivity				
	None	Sub Contracted (Yes/No)	Installed Quantity (MT)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/ MT)

Pipe rack module structure may include several components such as structural steel for framework, walkway, platform to support the piping, piping c/w (cooling water) valving. It also may include electrical tray, heat tracing and insulation.

Process Equipment Modules	Estimated Productivity			
	None	Quantity (MT)	WH	Total Installed Unit Cost ($/ MT)

Process Equipment Modules	Actual Productivity				
	None	Sub Contracted (Yes/No)	Installed Quantity (MT)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/ MT)

Building Modules	Estimated Productivity			
	None	Quantity (SM)	WH	Total Installed Unit Cost ($/ SM)

Building Modules are considered as 1 (or more) structural framework structures with a portion (or all of the structure) attached with a building cladding. The structures must be suitable for transport, and fabricated in a location remote to the final location. Examples of modules with buildings are: Electrical MCC buildings, Piping Manifold Buildings, etc.

Building Modules	Actual Productivity				
	None	Sub Contracted (Yes/No)	Installed Quantity (SM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/ SM)

Building Modules are considered as 1 (or more) structural framework structures with a portion (or all of the structure) attached with a building cladding. The structures must be suitable for transport, and fabricated in a location remote to the final location. Examples of modules with buildings are: Electrical MCC buildings, Piping Manifold Buildings, etc.

Figure 4.14 Additional Question for Module Installations

4.9 Scaffolding

Instructions

Please provide estimated and actual productivity for scaffolding:

Enter the ***estimated* total work-hours** required for **scaffolding installation**, the ***estimated* scaffolding work-hours divided by total direct hours**, and the ***estimated* total installed scaffolding cost** including direct labour, materials and equipment cost for installation at the time of project sanction (or as soon as available following sanction).

For ***actual*** productivity, please indicate whether the Scaffolding activity was ***subcontracted or not***. If work was both subcontracted and in-house, indicate which was more predominant.

Last, please provide the ***actual* total work-hours** (including rework) required for scaffolding installation, the ***actual* scaffolding work-hours divided by total direct hours**, and the ***actual* total installed scaffolding cost** which include material, labour and equipment cost for installation from both direct hire and subcontract.

Overall, please indicate the percentage amount of scaffolding procured by the owner. ____ %

Scaffolding	Estimated			
	None	Total Scaffolding Work- Hours	Scaffolding WH/ Total direct hours	Total Installed Scaffolding Cost ($)

Scaffolding	Actual				
	None	Sub contracted (Yes or No)	Total Scaffolding Work- Hours	Scaffolding WH/ Total direct hours	Total Installed Scaffolding Cost ($)

Scaffold Materials

- ◘ Free Issue to Contractor
- ◘ Rented
- ◘ Purchased & Included as part of Scaffold Cost

Figure 4.15 Additional Question for Scaffolding

6.4 Workforce Conditions

a) Percentage of workweek by workforce shifts and schedules:

Indicate on average, the predicted and actual percentage of the project's workforce working day, evening and night shifts, by work week schedules. If the actual percentage cannot be calculated, please provide your best assessment. Answer Unknown only if you cannot make a reasonable assessment. Percentages may be indicated in increments of 5 %.

As budgeted in AFE				
Work Schedule (days)	Days		Nights	
4-3	______%	◘ Unknown	______%	◘ Unknown
5-2	______%	◘ Unknown	______%	◘ Unknown
10-4	______%	◘ Unknown	______%	◘ Unknown
11-3	______%	◘ Unknown	______%	◘ Unknown
12-2	______%	◘ Unknown	______%	◘ Unknown
Other	______%	◘ Unknown	______%	◘ Unknown
Total	100 %		100 %	

Actual at project completion				
Work Schedule (days)	Days		Nights	
4-3	______%	◘ Unknown	______%	◘ Unknown
5-2	______%	◘ Unknown	______%	◘ Unknown
10-4	______%	◘ Unknown	______%	◘ Unknown
11-3	______%	◘ Unknown	______%	◘ Unknown
12-2	______%	◘ Unknown	______%	◘ Unknown
Other	______%	◘ Unknown	______%	◘ Unknown
Total	100 %		100 %	

b) Level of Overtime as % of total field Work-hours

Indicate below the planned and actual percentage of field work-hours classified as overtime.

Planned overtime	Actual overtime
______________% ◘ Unknown	______________% ◘ Unknown

If the ratio of Actual exceeds Planned overtime, please provide the reason why: ____

Figure 4.16 Additional Question for Workforce Conditions

c) Worker accommodations

Indicate below the planned and actual percentage of workers living in camps and with living out allowance (LOA).

Planned % of workers in camps	Actual % of workers in camps
_______________% ◘ Unknown	_______________% ◘ Unknown

Planned % of workers with LOA	Actual % of workers with LOA
_______________% ◘ Unknown	_______________% ◘ Unknown

d) Peak construction work force

Indicate the peak construction work force planned and achieved for this project by inputting the maximum number of working personnel at the jobsite at one time:

Planned Peak Work Force	Actual Peak Work Force
_______________ ◘ Unknown	_______________ ◘ Unknown

e) Indicate as a percentage below the planned and actual methods utilized by personnel for travel to the worksite.

Mode of Travel	Planned	Actual
Bus	___________% ◘ Unknown	___________% ◘ Unknown
Air	___________% ◘ Unknown	___________% ◘ Unknown
Personal Vehicle	___________% ◘ Unknown	___________% ◘ Unknown
Other	___________% ◘ Unknown	___________% ◘ Unknown
Total	100 %	100 %

f) Percentage of winter work:

What percentage of **winter work was performed in outdoor conditions from October 15 to April 15?** If the actual percentage cannot be calculated, please provide your best assessment. Answer Unknown only if you cannot make a reasonable assessment.

Planned Outdoor Work in Winter	Actual Outdoor Work in Winter
_______________% ◘ Unknown	_______________% ◘ Unknown

Figure 4.16 Additional Question for Workforce Conditions (Continued)

4.3 DEVELOPMENT OF THE REPORTING SYSTEM

4.3.1 Hierarchical Structure of Alberta Project Types

During the report development stage, the COAA and CII BM&M team surmised that norms of project performance such as cost schedule, productivity and management practices metrics would differ by project type. For example, it was believed that scaffolding work hours metrics norm of downstream projects would be much greater than those of upstream projects. Even with in the same group of projects, among upstream projects, norms of performance metrics of oil sands Steam Assisted Gravity Drainage (SAGD)[2] would also be different from those of oils sands mining/extraction depending on process unit components.

To address these issues and provide meaningful comparisons for each metric, a hierarchical structure of Alberta project types was developed, as shown in Table 4.5. Alberta oils sands development projects are classified in three levels. Level 1 is the broadest group of projects, then further divided into level 2 which are major project types, and to level 3 which is a group of specific process units.

As shown in Table 4.5, level 1 was divided into four major categories including upstream oil and gas, downstream oil and gas, natural gas, and pipeline projects. Upstream oil and gas is divided in level 2 into oil sands SAGD, oil sands mining, and oil production. Level 3 identify sub projects which can be either single or multiple process units based upon a common practice of Alberta oil sands projects. As common in Alberta, mega projects are commonly broken down to multiple smaller projects, which consisting of different process units. The

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[2] Steam Assisted Gravity Drainage (SAGD) – is a recovery technique for extraction of heavy oil or bitumen that involves drilling a pair of horizontal wells one above the other (http://en.wikipedia.org).

hierarchical structure is used to provide better comparison to specific project types, starting from comparison at the most detailed project level available.

Table 4.5 Hierarchical Structure of Alberta Project Types

Level 1	Level 2	Level 3
Upstream (Oil Exploration/ Production)	Oil Sands SAGD	Cogeneration
		Central Plant Processing Facilities
		Pad and Gathering
	Oil Sands Mining/ Extraction	Oil Sands Mining
		Central Plant Processing Facilities
Downstream	Oil Sands Upgrading	Naptha Hydrotreater Unit
		Hydrogen Plant
	Oil Refining	Utilities and Offsite
Natural Gas	Natural Gas Processing	
Pipeline	Process Pipeline	
	Pipeline SAGD	
	Pipeline (Gas Distribution)	

4.3.2 Comparison Algorithm of Alberta Project Performance

The COAA and CII development teams collaboratively created a comparison algorithm for the benchmarking reporting system in order to mine the database to enable comparisons amongst projects that are as similar as possible. The teams selected five major project characteristics which are considered to be significant. As shown in Tables 4.6 and 4.7, the five categories are project cost, project nature, project type-level 2, project type-level 1, and response type. The algorithm is designed to mine the database to a group of projects which has the closest five characteristics to obtain the most meaningful dataset for comparison within the constraints of data available. If the number of data in that group is not sufficient, the database will be successively rolled up in each criteria characteristic to “all”, starting from cost category, then project nature, project type-level 2, and finally project type- level 1. It should be noted that the algorithm for project performance and practices is designed to compare owner and contractor data separately, while the algorithm for engineering and construction productivity combines owner and contactor data.

Table 4.6 illustrates the comparison algorithm for project performance metrics such as cost, schedule, rework, changes, and also best practices. For project performance comparison, owner and contractor data are separated because of their differences in work scopes, and perspective in managing projects. After metric values are calculated for each project, metrics are then processed through the algorithm to find the closest specific data slice available. For example a project classified as an owner, $100M- $250M project, grassroots, oil sands SAGD, upstream enters 'loop 1' in Table 4.6. If the comparable dataset in the specific data slice has less than 10 projects or data from less than 3 companies, the comparison moved to 'loop 2' which combines all project cost categories to increase the number of comparison data.

Table 4.6 Comparison Algorithm of Alberta Project Performance Metrics

Loop #	Respondent Type	Level 1	Level 2	Nature	Cost Category
# 1 – no slices found, go to 2	Owner	Upstream	Oil Sands SAGD	Grassroots	$100-250MM
#2 – no slices found, go to 3	Owner	Upstream	Oil Sands SAGD	Grassroots	ALL
#3– no slices found, go to 4	Owner	Upstream	Oil Sands SAGD	ALL	ALL
4: Stop! Data Slice found with n=10!!	Owner	Upstream	ALL	ALL	ALL
#5	Owner	ALL	ALL	ALL	ALL
#6	ALL	ALL	ALL	ALL	ALL

A similar algorithm was applied for engineering and construction productivity comparison as shown in Table 4.7, but because engineering and construction productivity data are reported from contractor, the owner and contractor productivity data can be combined for benchmarking comparison. A second set of iterations was added to accommodate the additional comparisons. The primary benefit of this is to provide better comparisons in instances of limited data.

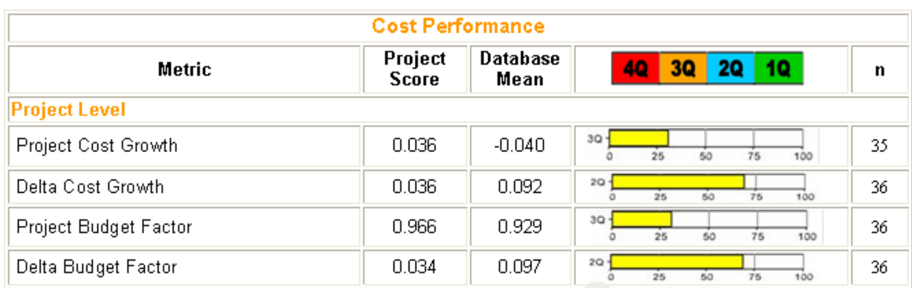
Table 4.7 Comparison Algorithm of Alberta Engineering and Construction Productivity Metrics

Loop #	Respondent Type	Level 1	Level 2	Nature	Cost Category
# 1 – no slices found, go to 2	Owner	Upstream	Oil Sands SAGD	Grassroots	$100-250MM
#2 – no slices found, go to 3	Owner	Upstream	Oil Sands SAGD	Grassroots	ALL
#3– no slices found, go to 4	Owner	Upstream	Oil Sands SAGD	ALL	ALL
4: Stop! Data Slice found with n=10!!	Owner	Upstream	ALL	ALL	ALL
#5	Owner	ALL	ALL	ALL	ALL
#6- Second Round with All Response Type	ALL	Upstream	Oil Sands SAGD	Grassroots	$100-250MM
#7	ALL	Upstream	Oil Sands SAGD	Grassroots	ALL
#8	ALL	Upstream	Oil Sands SAGD	ALL	ALL
#9	ALL	Upstream	ALL	ALL	ALL
#10	ALL	ALL	ALL	ALL	ALL

4.3.3 Understanding the Benchmarking Report

The benchmarking reports provide a participating company feedback on project performance. It compares the project against the most similar projects available for each individual metric. The organization uses this report to identify performance weaknesses and to set its target for continuous improvement.

Adopted from CII BM&M system, the comparisons for each metric are provided with the database mean and all comparable projects are organized into color-coded. For the purpose of this research, Alberta project performance metrics consist of cost, schedule, safety, change, field rework, engineering and construction productivity, and estimating accuracy of productivity rate and TIUC. A lower score generally indicates a better performance which is in the first quartile with green color coded. Figure 4.17 is an example of a cost performance metric report. For instance, this project has 0.036 in project cost growth which indicates that the project overran the budget by 3.6%. The comparable dataset has 35 projects with an average cost growth of -4.0%, meaning actual cost was 4% less than initially predicted. Overall, this project is 3rd quartile on cost growth.



Cost Performance

Metric	Project Score	Database Mean	4Q 3Q 2Q 1Q	n
Project Level				
Project Cost Growth	0.036	-0.040	3Q	35
Delta Cost Growth	0.036	0.092	2Q	36
Project Budget Factor	0.966	0.929	3Q	36
Delta Budget Factor	0.034	0.097	2Q	36

Figure 4.17 An Example of Project Cost Metrics

Figure 4.18 shows a sample of engineering productivity metrics. In this figure, the unit rate is provided that divides the total design work hours by its corresponding issued for construction (IFC) quantity.

Structural Steel						
Metric	Design Hours	IFC Quantity (MT)	Unit Rate (Design Hours/ MT)	Database Mean	4Q 3Q 2Q 1Q	n
Structural Steel	18,113	2,941	6.16	8.94	2Q	21
Pipe Racks & Utility Bridge	13,585	1,949	6.97	4.20	3Q	12*
Combined Structural Steel and Pipe Racks & Utility Bridge	31,698	4,890	6.48	10.13	1Q	29
Miscellaneous Steel	4,529	522	8.68	15.33	2Q	22
Total Structural Steel						
: Total Structural Steel Productivity Rate	**36,227**	**5,412**	**6.69**	**12.42**	1Q	36

Figure 4.18 Sample of Project Engineering Productivity Metrics

Figure 4.19 provides a sample of the key report for construction productivity. In this figure, calculations and comparisons for each metric are provided in much the same way as engineering productivity. Specific for Albert projects, additional construction productivity metrics are presented for estimated work hours, estimated installed quantity, estimated and total installed unit cost. The purpose is to enhance the ability to compare estimates of construction productivity rate and total installed unit cost (TIUC) for every work discipline which is generated at sanction with actual data from completed projects. For example, Figure 4.19 shows an actual total steel productivity rate (29.64 work hours/ metric ton) with a second quartile performance or roughly the 70th percentile when compared to the database of similar projects. Similarly, a lower score generally indicates better performance. So, the result indicates that about 30% of projects in the comparison slice are more productive (less hours spent on installing a ton of structural steel).

Structural Steel						
Metric	Wk-Hrs	Installed Quantity (MT)	Unit Rate (Wk-Hrs/MT)	Database Mean	4Q 3Q 2Q 1Q	n
Structural Steel	15,304	637	24.03	23.74	3Q	12*
Pipe Racks & Utility Bridge	5,391	289	18.64	28.58	2Q	19*
Miscellaneous Steel	11,882	173	68.57	51.14	3Q	11*
: Total Structural Steel Productivity Rate	**32,577**	**1,099**	**29.64**	**30.80**	2Q	14
	Est. Wk-Hrs	**Est. Quantity (MT)**	**Est. Unit Rate (Wk-Hrs/ MT)**		4Q 3Q 2Q 1Q	n
: Total Estimated Structural Steel Productivity Rate	**29,000**	**1,000**	**29.00**		2Q	14
	Actual ($/MT)	**Estimated ($/MT)**	**Actual DB Mean ($/MT)**		4Q 3Q 2Q 1Q	n
: Total Installed Unit Cost	**3,200**	**3,000**	**3,100**		1Q	14

Figure 4.19 Sample of Project Construction Productivity Metrics

Next, an estimated total steel productivity rate (29 work hours/metric ton) is shown to be in roughly the 70th percentile when compared to the database of similar projects. Since a lower value indicates better performance. So, the result indicates that about 30% of projects in the comparisons slice (N=14) has more accurate estimates for structural steel productivity (close to the mean of actual total steel productivity rate, 30.8 WH/MT). Lastly, an estimated structural steel TIUC ($3,000 CDN/Metric ton) is in the first quartile or roughly the 90th percentile indicating that about 10% of projects in the comparisons slice (*N*=14) had more accurate estimates (close to the mean of actual structural steel TIUC, $3,100 CDN/metric ton).

This study applied the CII BM&M system for comparison of practice metrics. As mentioned previously, 14 best practices are scored in a range of 0 to10, with a higher number indicating superior implementation of the practice. As shown in Figure 4.20, a project with a score of 8.929 on the use of Front End Planning (FEP) falls within the 2nd quartile or roughly 70th percentile when compared to 36 similar projects. The result indicates that about 30% of projects in the comparisons slice (N=36) had higher level of FEP implementation than this project. Thus, the project team implemented FEP relatively well.

Metric	Project Score	Database Mean	4Q 3Q 2Q 1Q	n
Front End Planning	8.929	7.557	30 (0 25 50 75 100)	36

Figure 4.20 An Example of Practice Metrics

CHAPTER 5: ANALYSIS OF ALBERTA METRICS

This chapter provides descriptive statistics for the 37 projects in Alberta submitted in this study for benchmarking. A description of how the data were prepared and analyzed is also included. The results offer an overview of the data characteristics by project size, type, and nature. The second section includes a distribution of the metrics data with mean, median, range and quartile charted by using box and whisker diagrams. This chapter also presents a comparison of project performance and productivity between Alberta and U.S. projects to examine the strength and weaknesses of Alberta-based projects.

By reviewing the analysis results presented in this chapter, the first hypothesis of this study is established as shown in Figure 5.1. The first hypothesis states that additional specific metrics can be developed to measure project performance tailored to the challenges of Alberta projects. The qualitative evaluation of the comprehensibility of these metrics is justified by expert opinion. Next, the quantitative evaluation of these metrics is also made by reviewing metric distributions and norms, and the metrics are validated if they provide reasonable information by industry experts. Last, the analysis of project performance comparisons between Alberta and U.S. projects substantiates the validity of the metrics that these metrics provide meaningful comparisons against an external database such as the CII BM&M data.

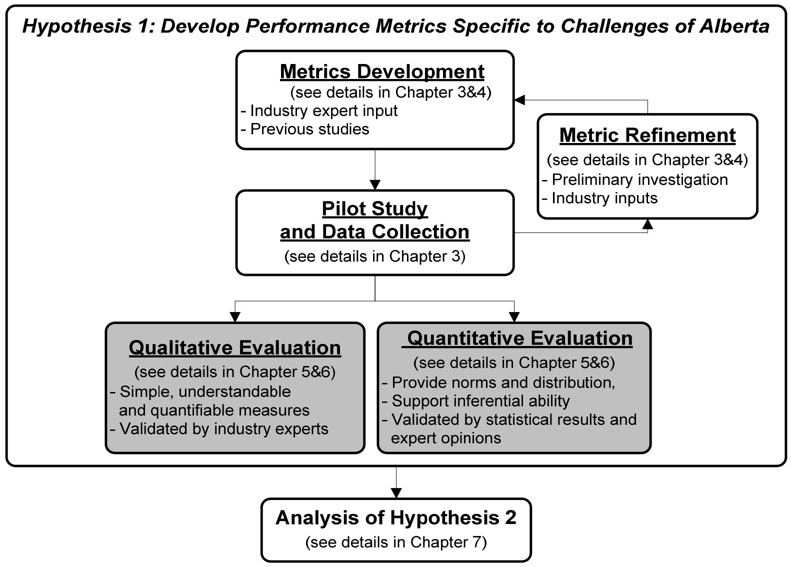


Figure 5.1 Steps for Analysis of Hypothesis 1

5.1 DATA PREPARATION

Data preparation was a key step for data analysis, given that there are about 500 variables included in the CII and Alberta datasets used in this study. These variables store project information, including cost, schedule, and engineering and construction productivity data, which were stored in a secured Microsoft SQL Server 2005® database. All data tables were exported to Microsoft Excel® because of its compatibility with various statistical packages commonly used for data analysis. The most critical component of the data preparation was to merge the CII and Alberta project data, and convert the units of measurements for the engineering and construction productivity data as well as currency. These two tasks were mainly performed using Microsoft Excel® and Microsoft Access®. Finally, the data analyses were performed using MINITAB 15, SPSS 16 and SAS 9.1.3. Due to varying functionality, multiple statistical packages were used to accomplish the analytical tasks.

5.2 DESCRIPTION OF ALBERTA DATASET

As shown in Figure 5.2 from November 2005 to October 2008, data from 78 projects were recorded by 19 COAA member companies: ten owners and nine contractors. Ultimately, 37 projects were completed by the deadline and analyzed in this study. The 41 remaining projects are for the most part projects whose end date exceeded this study. Future research can be performed on these projects to realize some of the recommendations of this study. Some of the projects in progress may never be submitted due to project cancellation or other factors.

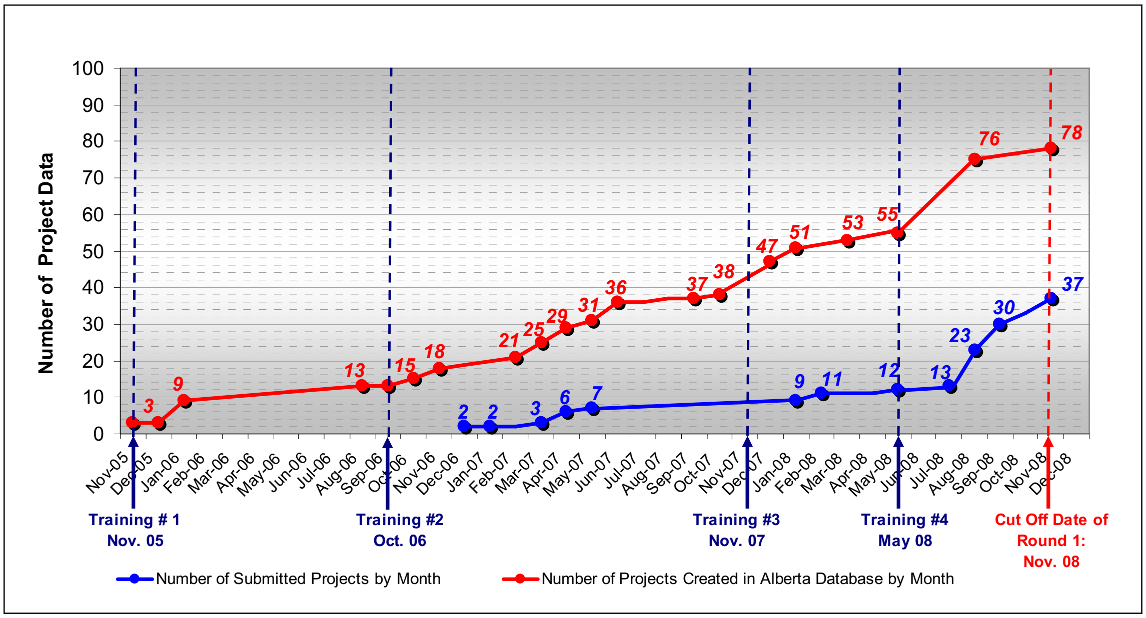


Figure 5.2 Number of Projects in Alberta Database by Month

Figure 5.3 illustrates the categorization of the 37 submitted projects by respondent types. There were 28 projects submitted by six different owners, while 9 projects were provided by three different contractors.

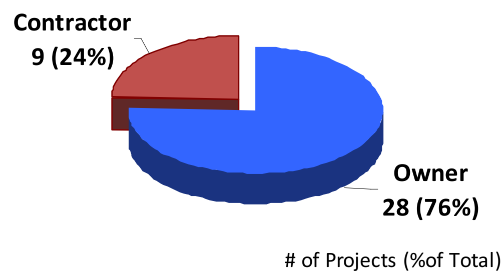


Figure 5.3 Number of Submitted Projects by Respondent Types

Figure 5.4 presents the number of submitted projects by projects types. As mentioned in Section 4.2, these project types were defined by the COAA benchmarking committee and Alberta industry experts. It can be seen that the majority of submitted projects are oil sands upgrading and oil sands SAGD.

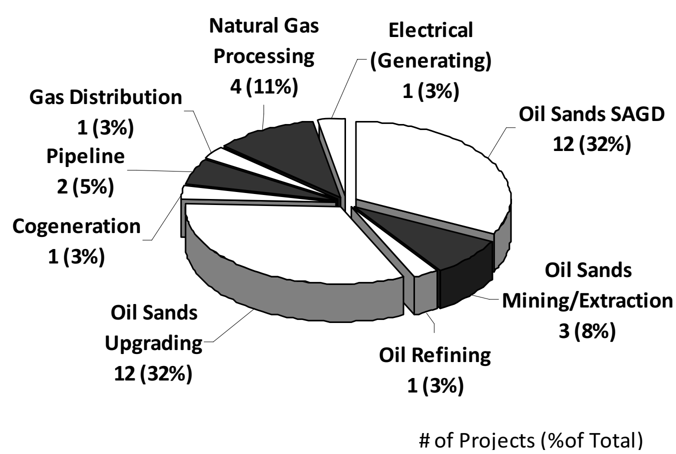


Figure 5.4 Number of Submitted Projects by Project Types

Due to the fact that most Alberta projects are mega size with durations 3 to 5 years long, the data submission was allowed for two milestones: once at project sanction and again at project completion. Table 5.1 presents the 37 submitted projects broken down by respondent types, project types, and project submittal period. It can be seen that the majority of projects were submitted by owners at completion.

Table 5.1 Number of Submitted Projects by Owners and Contractors at Project Completion and Sanction

Project Types	Number of Projects	Submitted at			
		Sanction		Completion	
		Owner	Contractor	Owner	Contractor
Oil Sands Upgrading	12	6	2	3	1
Oil Sands SAGD	12	1	-	8	3
Natural Gas Processing	4	-	-	1	3
Oil Sands Mining/Extraction	3	2	-	1	-
Pipeline	2	-	-	2	-
Cogeneration	1	-	-	1	-
Oil Refining	1	-	-	1	-
Electrical (Generating)	1	1	-	-	-
Gas Distribution	1	-	-	1	-
Total	**37**	**10**	**2**	**18**	**7**

Figure 5.5 shows the distribution of the 37 submitted projects at the system benchmark milestones including sanction or completion by total project cost category ($CDN). It should be noted that the total project cost is defined in this study as the total installed cost for owners, while contractors only report the total cost of their scope of work. The project costs shown in Figure 5.5 have been converted to 2007 $CDN to produce a valid performance comparison basis. RS Means was used to adjust costs reported from the mid-point of overall project duration to July 2007. It can be seen that majority of submitted projects for both sanction and completion are mega projects with project cost exceed $1B CDN. All submitted projects were completed after 2003. Note that only 35 projects are shown in Figure 5.5 since two projects did not provide project cost information.

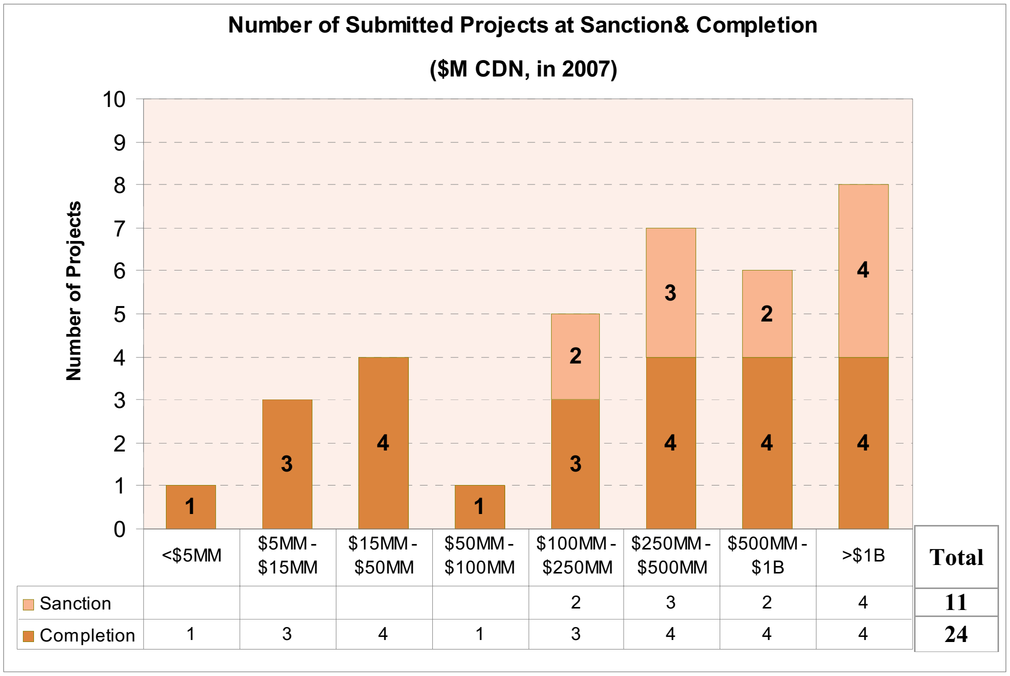


Figure 5.5 Number of Projects Submitted at Sanction and Completion by Project Cost Category ($CDN in 2007 Dollars)

As a common practice, mega projects are broken into several smaller projects (subprojects) to facilitate management. As a result, among the 37 submitted projects, half were subprojects that were submitted separately. They were treated as individual projects for data analysis in this study. As shown in Figure 5.6, the 37 submitted projects are mostly grassroots and used parallel prime and design-build (DB) delivery systems. Every project used cost reimbursable contracts. A glossary of terms used in this study is provided in Appendix A. However, it should be noted that due to the limited number of data points, the lowest level of analysis will be presented for categories with 10 or more projects, in accordance with the CII and COAA confidentiality policy.

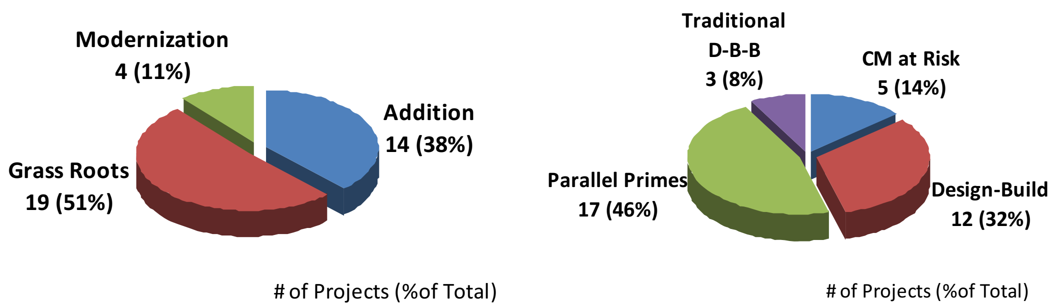


Figure 5.6 Number of Submitted Projects by Project Nature and Project Delivery System

5.3 EVALUATION OF ALBERTA SPECIFIC METRICS

The purpose of this analysis is to confirm the first hypothesis of this study regarding the meaningfulness of the Alberta specific metrics developed in this research. A descriptive statistic for each metric was presented to illustrate the distributions and norms calculated from the dataset. To examine if the metrics are reliable measurements and provide meaningful results, each metric was judged against a set of criteria, and then confirmed by expert opinion as described below.

5.3.1 Evaluation of Metrics by Statistical Result

The metric norms and distributions were produced and evaluated. First, metric norms should be reasonable and within acceptable range as described by industry experts. Second, metric distributions were investigated through box and whisker plots (boxplot) to examine whether each metric's distribution is normally distributed or not. As explained in Appendix D, boxplot is a convenient way of graphically depicting data characteristics such as central tendency, distribution, and outliers. The horizontal line in the box represents the median of the data. If the median line within the box is not equidistant from the hinges, then the data is skewed. The data fall beyond the whiskers or 1.5 IQR of the third quartile or below 1.5 IQR of the first quartile are considered as extreme values or outliers. When the distribution is not normally distributed, there is a tendency for issues surrounding the clarity of the terminology used to describe the metric and data validation. If this is the case, the definition of the particular metric may need to be refined or norms should be presented only for selected breakouts. However, some metrics are not necessarily normally distributed, such as the safety metric, where most of the data is skewed towards zero.

5.3.2 Evaluation of Metrics by Expert Opinions

The descriptive statistics and boxplots are used as a high level investigation on the metrics; however the final evaluation is determined by expert opinions based on their experience according to the step for the first hypothesis test shown in Figure 5.1. The box and whisker plots, as described in Section 5.3.1, for each metric were produced and presented to the COAA benchmarking committee, which consisted of 12 representatives from 5 different owner and 3 contractor companies. Then, the results were presented to the industry at the COAA Best Practice conference, with more than 60 Alberta industry experts in attendance, and also to the COAA Board of Advisors. Overall, most of the industry participants agreed that the metrics produce simple and understandable measurements and provide meaningful information to the industry to improve project performance, productivity and project estimates. However, some comments were gathered that further action and improvements were needed. These comments are presented in the following section.

5.3.3 Analysis Results

In this section, the preliminary analysis results from construction indirect cost work hours, construction indirect cost growth, and scaffolding metrics are presented and discussed in detail to illustrate their associated norms, distributions from analysis and the expert evaluations. Construction indirect work hours and cost growth metrics were selected because impacts on indirect work were reported to be one of the most significant issues of interest to the Alberta experts. This is because indirect work highly impacts project cost overruns and low construction productivity. In addition, the scaffolding metric is presented because it was identified by the experts as needing readjustment in order to produce meaningful results. While the other metrics studied are not shown in detail in this section, they are presented in the following chapter to support further analysis.

It is worth mentioning that both owner and contractor data were combined in the data analysis at this point of the study due to the limited number of project data. However, the results are still considered meaningful because most of Alberta owner companies collaborated with their contractor on data entry.

5.3.3.1 Construction Indirect Work Hours

Using boxplot to illustrate the mean, median, quartiles, range, outliers, and the distribution of construction indirect work hours metrics as shown in Figures 5.7. The construction indirect work hours metrics is defined as a proportion of total construction indirect work hours and total construction direct work hours. The *N* value below the graph indicates that there are 20 projects data in the Alberta dataset reporting on this metric.

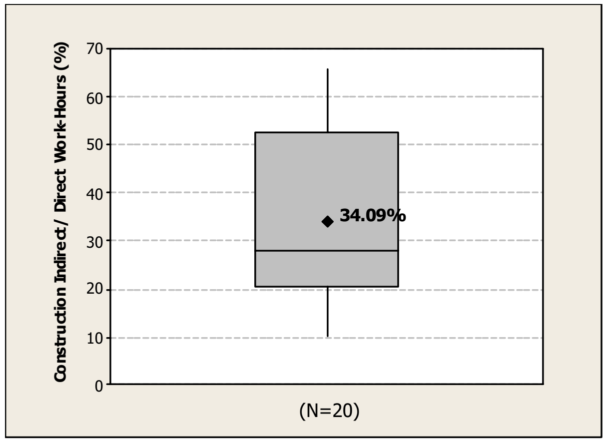


Figure 5.7 Construction Indirect/Direct Work Hours (%)

Alberta Specific Metrics	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
						Statistic	Std. Error	Statistic	Std. Error
Construction indirect/Direct work hours (%)	20	10	65.73	34.09	17.554	.365	.501	-.673	.972

Figure 5.8 Statistical Results of Construction Indirect/Direct Work Hours (%)

It can be seen from the preliminary results shown in Figure 5.7 that on average, the amount of indirect construction work hours to direct work hours for 20 Alberta-based projects in the dataset is 34% with variation ranging from 10 to 65%. These results are in line with industry perception that the ratio of indirect/direct work hours is about 20 to 30% in Alberta. This is comparatively higher than average of U.S. projects, which is believed to be about 10 to 20%. The results are also consistent with the research done by Robinson (2002) indicating that on average, Alberta projects exhibit higher proportions of construction indirect work hours due to remote site location and extreme weather. However, the wide variance of the indirect work metric's distribution may be due to a discrepancy between the definition introduced in this study and the owners and contractor proprietary definitions of indirect work. Additionally, the variance can be attributed to the range of project locations, from remote areas to local works. Projects in remote areas require significantly higher construction indirect work hours.

Also, the boxplot provided in Figure 5.7 shows that the majority of the data reported lie on the lower range (in between 20% and 50 %). This is indicated by the median line within the box, which is close to the lower edge indicating positively skewed data. However, the test statistics as shown in Figure 5.8 indicate that the distribution is considered normally distributed, which is supported by the skewness statistic of 0.365. This statistic falls within the acceptable range of -3 to +3, which indicates a slightly positive skew. In addition, of all of the reported projects, there is no indication of a project with extreme data or outliers. Outliers are defined as data points located beyond the range of the whiskers on a boxplot.

As described above, the results confirm that the indirect work metric is a meaningful measure, and it provides useful information to project teams. However, upon inspection of the results, the COAA benchmarking committee has suggested refinement of the indirect work account (Appendix G) in order to enhance the metric's capability to produce norms for different indirect work items, such as offsite construction work hours and the work hours spent on site preparation to facilitate project execution.

5.3.2.2 Construction Direct and Indirect Cost Growth

Figure 5.9 shows the distributions of cost growth for construction direct and indirect costs for 16 Alberta projects. Construction cost growth refers to the deviation of actual direct cost from estimates.

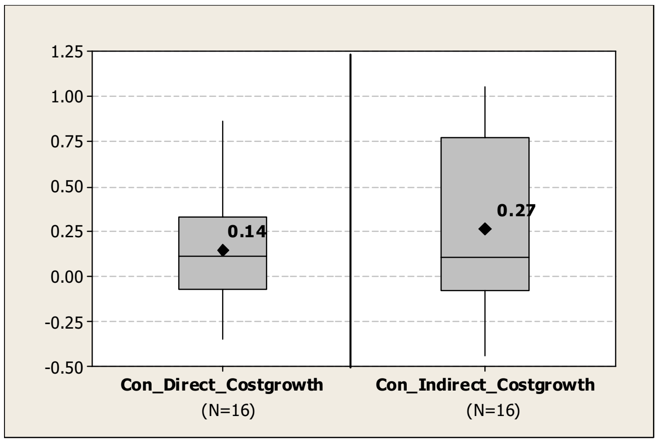


Figure 5.9 Construction Direct Cost Growth and Construction Indirect Cost Growth

Alberta Specific Metrics	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
						Statistic	Std. Error	Statistic	Std. Error
Construction direct cost growth	16	-.349	.861	.145	.320	.777	.564	.622	1.091
Construction indirect cost growth	16	-.435	1.054	.266	.487	.480	.564	-1.025	1.091

Figure 5.10 Statistical Results of Construction Direct Cost Growth and Construction Indirect Cost Growth Metrics

The preliminary data analysis results show that the average direct construction cost growth is about 14%, while indirect construction growth is 27%. The result indicates that indirect cost growth on average is approximately 2 times greater than direct, with large variance. This result is in line with the perception of experts; it reveals problems with managing indirect work. The wider range of indirect cost growth may be caused by insufficient planning, or poor estimating for factors such as unexpected weather.

Also, the boxplot as shown in Figure 5.9 and the skewness statistics in Figure 5.10 indicate that the distributions of both construction direct cost growth and indirect cost growth are considered normally distributed. The skewness value statistics indicate slightly positive skew for both direct and indirect cost growth (0.777 and 0.48, respectively). In addition from the reported projects, there is no indication of a project with extreme data or outliers. Therefore, it can be confirmed that the cost growth metrics provide meaningful performance measurement.

5.3.3.3 Scaffolding Work Hours/Direct Construction Work Hours (%)

Figure 5.11 shows the distribution of 18 Alberta projects which reported their scaffolding data. The scaffolding metric is defined as a proportion of time spent on scaffolding work as a percentage of total direct construction work hours. The preliminary results of this metric illustrates that the metric needs to be improved. The average is approximately 8.6% of total direct work hours for Alberta projects. This result was too low as indicated by the experts because from their experience on previous projects, scaffolding is a more costly component for Alberta large EMR projects with averages usually greater than 15%.

The boxplot shown in Figure 5.11 together with the skewness statistic shown in Figure 5.12 indicates that this metric is considered normally distributed; however, the skewness statistic indicates a slightly positively skewed distribution. It should be noted from Figure 5.11 that most of the data points are lower than 10%, also, there is an indication of extreme data. Further investigation of those low and extreme data points suggested that it was due to different types of process units reported. The projects in the low range are mainly composed of construction of SAGD well pads, pipelines, utilities and offsite (i.e., assess roads) and oils sands mining, which require significantly less scaffolding work when compared to construction of hydrotreaters, cokers and other refining operation units. As a result, the industry experts suggested for benchmarking purpose that the scaffolding metric should be separated by project type and process unit prior to producing norms for the metric.

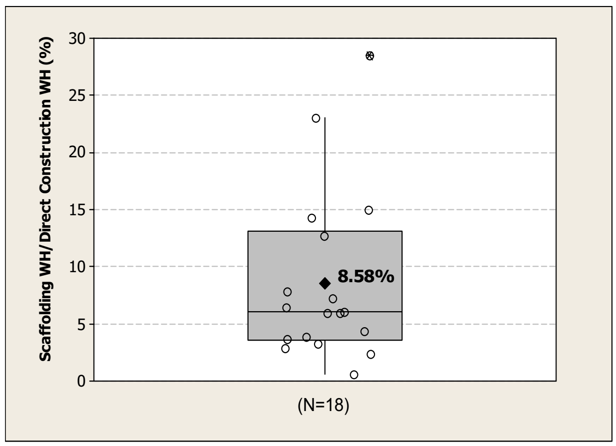


Figure 5.11 Scaffolding Work Hours/Direct Construction Work Hours (%)

Alberta Specific Metrics	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
						Statistic	Std. Error	Statistic	Std. Error
Scaffolding work hours/ Direct work hours	18	.600	28.500	8.173	7.465	1.607	.524	2.242	1.014

Figure 5.12 Statistical Results of Scaffolding Work Hours/Direct Construction Work Hours (%) Metric

5.3.4 Summary of Analysis Results

The same statistical analysis and evaluation were performed for remaining Alberta specific metrics. The results are summarized in Table 5.2.

Table 5.2 Summary Descriptive Statistics of Alberta Specific Metrics

Alberta Specific Metrics	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
						Statistic	Std. Error	Statistic	Std. Error
1. Construction indirect/Direct cost (%)	18	12.360	81.747	38.596	19.495	.915	.536	.593	1.038
2. Construction indirect/Direct work hours (%)	20	10.00	65.730	34.09	17.554	.365	.501	-.673	.972
3. Construction direct cost/Total project cost (%)	18	5.02	44.98	20.707	11.651	.578	.536	-.868	1.038
4. Construction direct cost growth	16	-.349	.861	.145	.320	.777	.564	.622	1.091
5. Construction indirect cost growth	16	-.435	1.054	.266	.487	.480	.564	-1.025	1.091
6. Workforce predictability	22	.783	2.333	1.277	.391	1.592	.491	2.480	.953
7. Scaffolding work hours/ Direct work hours	18	.600	28.500	8.173	7.465	1.607	.524	2.242	1.014
8. Modularization cost/Total project cost (%)	36	0	50	18.06	13.695	.372	.393	-.685	.768
9. Offsite construction labor Hours/Total construction hours (%)	33	0	40	19.39	13.214	.031	.409	-.987	.798
10. Overtime work hours/Total field work hours (%)	14	3	100	23.07	24.209	2.713	.597	8.818	1.154
11. Percentage of work outdoor in winter	18	0	70	37.33	16.234	-.229	.536	1.000	1.038
12. Estimating accuracy of total concrete productivity (WH/metric ton)	9	.887	3.735	1.70781	.862376	1.842	.717	3.976	1.400
13. Estimating accuracy of total concrete unit cost ($/m^3$)	10	.590	3.482	1.33616	.866947	1.971	.687	4.220	1.334
14. Estimating accuracy of total steel productivity	17	.348	2.558	1.21633	.564430	.848	.550	.606	1.063
15. Estimating accuracy of total steel unit cost ($/metric ton)	15	.273	1.526	1.10898	.314143	-1.235	.580	2.545	1.121
16. Estimating accuracy of large bore piping productivity (WH/meter)	10	.327	1.615	1.04434	.362997	-.450	.687	.617	1.334
17. Estimating accuracy of large bore piping unit cost ($/meter)	8	.330	1.901	1.01926	.431163	.845	.752	3.351	1.481

Note: Shaded cells indicate high kurtosis

As seen in Table 5.2, most of metrics are acceptable to be normal distribution as indicated by a value of the skewness statistic between -3 and +3 with zero representing perfectly normal distribution. In addition, the results indicate that the kurtosis, the measure of how peaked or flat a distribution is, values falling within a range of -3 to +3. It denotes that the observed data clustered near the average. If the kurtosis value exceeds -3 and +3, this signifies that fewer observed data are clustered near the average and more populate the extremes, far above or far below the mean. Four metrics fall beyond the acceptable kurtosis range on the positive side which are 1) overtime work hours/total field work hours (%), 2) estimating accuracy of total concrete productivity (WH/m^3), 3) estimating accuracy of total concrete unit cost (\$/m^3), and 4) estimating accuracy of large bore piping unit cost (\$/meter). The kurtosis results indicate that majority of projects in the dataset experienced high values on these four metrics. Although these four metrics have kurtosis values higher than -3 indicating that they do not have flat nor negative distributions. Therefore, they are still useful for further analysis and are capable of producing acceptable results.

As described above and together with the by industry experts, these evidences confirm that the metric is evaluated as meaningful measures and provide useful information to the project teams. However, the COAA benchmarking committee suggested to collected more data on metric related to estimating accuracy. The refinement of these metrics may be needed since the distributions with large number of sample size are generated.

5.4 COMPARISON OF PROJECT CHARACTERISTICS, PERFORMANCE AND PRODUCTIVITY BETWEEN ALBERTA AND U.S. PROJECTS

A primary focus of the data analysis in this section is to establish the second hypothesis of this study which is to confirm the reliability of the metrics. If the metrics are found to provide meaningful comparison results to those metrics of U.S. project performance, those metrics are confirmed to be reliable for measurement of large EMR project performance. Due to the differing project environments, the comparison analysis on project performance, engineering and construction productivity in this section is not intended to identify which group yields superior performance. Instead, the comparison documents the differences in characteristics, productivity rate, management practices, and the project execution processes between U.S. and Alberta-based projects. Also, it provides insight concerning how challenging factors contribute to project performance.

The performance and productivity comparisons were illustrated by using boxplots along with statistical tests, tests of mean difference (t-test) and Levene's test for equality of variances. Although the Alberta dataset sample size is quite small when compared to the U.S. dataset, the comparisons support the perceptions that Alberta projects differ from other conventional large EMR projects. The results also provide valuable information on undiscovered differences between Alberta project management and that of the U.S.

Overall, the results in this section confirm the perception of Alberta industry experts that project in that region tend to have significantly higher cost and schedule overrun and lower construction productivity (field labor productivity) than U.S. based projects. This is because these projects are large scale northern climate projects which are executed in remote areas afflicted by severe weather. Despite the characteristic cost and schedule overruns, the analysis results indicate a similar rate of engineering productivity between Alberta and U.S. projects.

5.4.1 Comparison of Project Characteristics between Alberta and U.S. Projects

To obtain comparisons of project performance in Alberta with projects executed in the United States using the CII Benchmarking and Metrics (BM&M) database, U.S. projects are limited to projects with an adjusted total installed cost greater than $50 million (CDN), normalized to 2007. Concerned that a broad range in project sizes may skew the performance comparison results, projects valued at $50 million (CDN) or greater were selected for comparison from the CII BM&M project dataset. This sampling from the CII BM&M dataset is large enough to provide meaningful comparison results.

The three project characteristics metrics which are project size ($), construction cost/ field work hours ($/WH), and contingency budget (%) were examined primarily to demonstrate differences between U.S. and Alberta-based projects. Based on past research and benchmarking experience, the differential project size is a significant factor in quantifying performance and should be considered in understanding the analyses presented in this section. Therefore, the analysis in this section started with the comparison of the project sizes between these two datasets to provide information to facilitate the data analysis performed in this section.

5.4.1.1 Project Size ($)

Figure 5.13 compares the distribution of project sizes on Alberta-based and U.S.-based large EMR projects in this study in terms of project cost. The symbol ♦ is used to indicate arithmetic mean and the symbol * is used to indicate the median of a particular group. As shown in Figure 5.13, the distributions indicate that the majority of U.S. projects are in the range of $100M to $200M, which is comparatively smaller than Alberta projects. in this dataset. In addition, the average project size of the 154 U.S. large EMR projects is $166.36M, which is notably smaller than the 23 Alberta-based projects ($367.83M). The results from the *t*-test indicate that the average project size of Alberta projects in this dataset is statistically significantly larger than U.S. projects in the dataset (*p*=0.03). Due to the large variance associated with this small sample size, there is a high likelihood that the statistically significant results achieved in this study may be proven false. Therefore, the author's recommendation is that the significance of the mean difference be verified with a larger sample size.

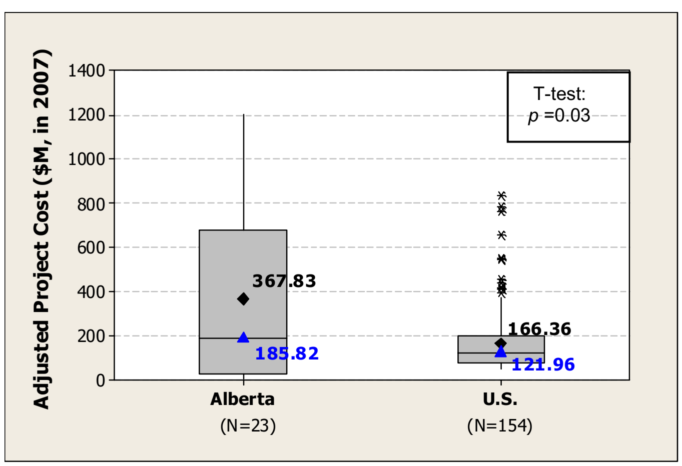


Figure 5.13 Comparison between Alberta and U.S. - Project Size ($Million CDN, in 2007 Dollars)

5.4.1.2 Construction Cost / Field Work Hour ($/WH)

Figure 5.14 compares the rate of spending money ($) on a project per field work hours of 17 projects in Alberta and 29 projects in the U.S. Project data show statistically significant higher rates of spending on Alberta projects than those in the U.S. with p=0.01. On average, Alberta projects spent $144.35/WH, compared to $52.23/WH spent on U.S. projects. In general, these results reveal that Alberta projects tend to invest more intensively than U.S. projects to accomplish project objectives and meet crashed schedules. On the other hand, this result suggests inherent inefficiencies due to remote location, harsh environment and perhaps planning practices. It should be noted that the conclusions gleaned from this preliminary data analysis should be made prudently due to a limited amount of data and the potential influence of the type of projects in the dataset.

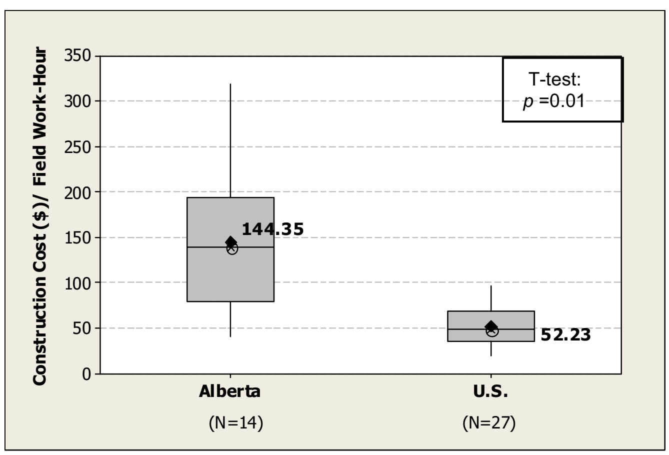


Figure 5.14 Comparison between Alberta and U.S. - Construction Cost / Field Work Hour ($/WH)

5.4.1.3 Contingency Budget (%)

Figure 5.15 compares the amount of contingency, which refers to the planned contingency budget divided by total project cost expressed as a percentage. As depicted in Figure 5.15, project data show a slightly higher than average contingency rate (8.04%) for Alberta-based projects when compared to U.S. projects (7.73%); however, the difference is not statistically significant (p=0.74). The results from the preliminary data analysis show that Alberta project teams underestimate the negative impacts and the likelihood that risks will occur. From the discussion with industry experts, most responded that they used 5% contingency as a rule of thumb which is the same as common practice in the U.S. However, they realize that it might not be applicable due to the unique challenges of their projects. The risk factor in Alberta projects is significant and more difficult to manage successfully. These risks need to be better quantified to properly manage the projects and react to problems as they arise.

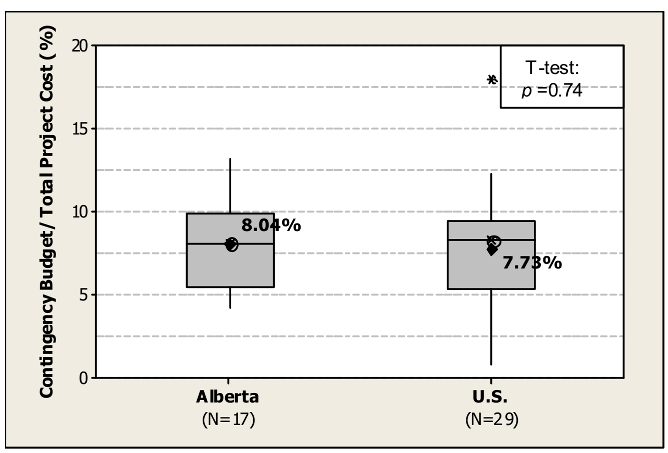


Figure 5.15 Comparison between Alberta and U.S. - Contingency Budget (%)

5.4.2 Comparison of Project Performance between Alberta and U.S. Projects

To compare project performance between Alberta and the U.S., similar analyses were performed on the selected metrics: project cost growth, schedule growth, development change cost factors, scope change cost factor, total change cost factor, and rework factor. These metrics were selected by industry experts as being of particularly high interest with respect to overall picture of project performance. For these performance metrics, the lower numbers indicate better performance. As the summary of *t*-test results shown in Table 5.3, it indicates that Alberta-based projects have poor cost, schedule, including development and scope change when compared to U.S.-based projects.

Table 5.3 Summary of T-Tests on Project Performance between Alberta and U.S. Large EMR Projects

Project Performance and Metrics	N		Mean		Worse on Alberta	*p*-values from T-Test
	Alberta	U.S.	Alberta	U.S.		
Project cost growth	24	153	0.19	0.03	✓	0.018*
Design phase cost growth	10	80	2.40	1.56	✓	0.523
Construction phase cost growth	19	129	0.12	0.08	✓	0.509
Project schedule growth	24	151	0.17	0.03	✓	0.007*
Development change cost factor	11	7	0.06	0.00	✓	0.141
Scope change cost factor	13	10	0.02	0.00	✓	0.374
Total change cost factor	15	91	0.06	0.06	-	0.583
Rework factor	11	54	0.03	0.03	-	0.813

Note: * indicates metrics with statistical significance of *t*-test at α level of 0.05

The detail analysis of comparison of the metrics listed in Table 5.3 with their statistical analyses techniques, boxplots, t-test, assumption tests and Levene's test for equality of variances were provided and discussed in the following section.

5.4.2.1 Project Cost and Schedule Growth

Figures 5.16 and 5.17 compare project cost growth and project schedule growth. The project cost growth metric is a ratio of the project cost overrun from original project budget, similarly the project schedule growth is a ratio of schedule overrun from the estimated total project duration. As the results of the preliminary analysis on the dataset show in Figures 5.16 and 5.17, on average, Alberta-based projects experienced 19% project cost growth and 17% project schedule growth, while U.S. projects experienced 3% and 6% cost and schedule growth, respectively. Additionally, these figures show that the Alberta-based projects experience a much wider range of performance (e.g. -27% to 69% for cost growth and -15% to 35% for schedule growth) when compared to projects executed in the U.S. This may suggest that Alberta projects are less well-controlled or that they are more difficult to predict as a consequence of inaccurate project estimates. Although the results are statistically significant, the Alberta dataset is small and the results may change as the dataset expands.

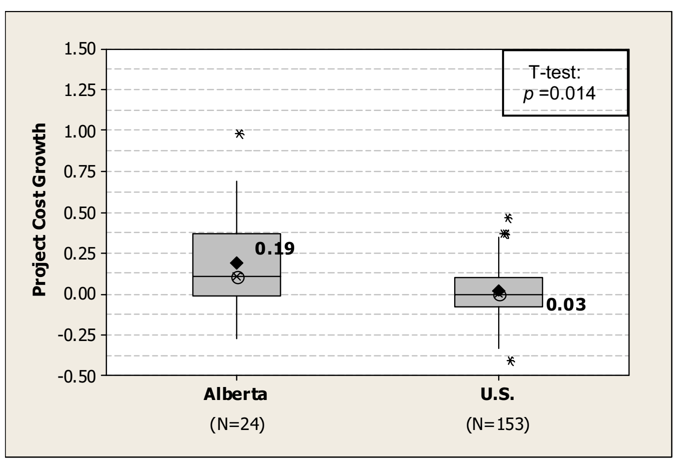


Figure 5.16 Comparison between Alberta and U.S. - Project Cost Growth

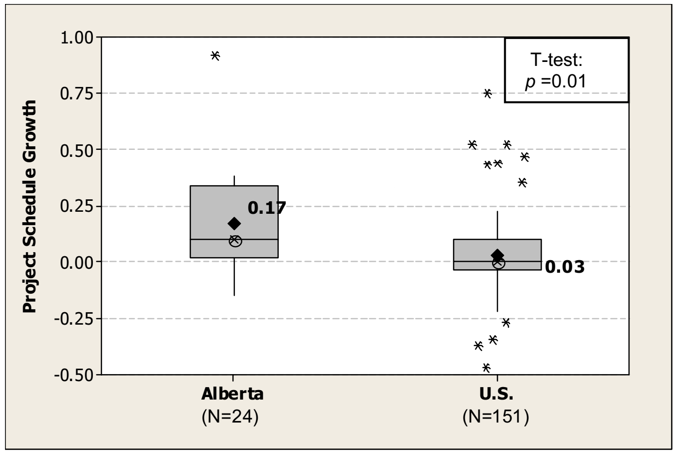


Figure 5.17 Comparison between Alberta and U.S. - Project Schedule Growth

Figure 5.18 provides computational outputs from SPSS® used to perform the *t*-test. In this analysis, *t*-test was used to evaluate whether the means of project cost growth between Alberta and U.S. projects are statistically different from each other, similarly to project schedule growth. The Levene's test was used to check if the variances are significantly different between the groups. The outputs from t-test provide p-values for both cases of "equal variances assumed" and "equal variance not assumed." If Levene's test is statistically significant at $\alpha<0.05$, then the results indicate equal variances are not assumed between two groups. The *t* statistics and *p*-value of "equal variance not assumed" will be used to determine the differences in the means are significant. An estimation procedure for the t-test will be adjusted when equal variances are not assumed. As seen in Figure 5.18, the Levene's test indicates that equal variances are not assumed for both project cost and schedule growth ($p<0.05$), thus the *p*-values for "equal variances not assumed" were used as results of *t*-test. This means that the null hypothesis of equal means between two groups was rejected. It can be concluded that the difference between project cost growth and schedule growth between Alberta and U.S. projects are statistically significant with $p=0.02$ for cost growth and p=0.01 for schedule growth. Again, it should be noted that a larger sample size is required to produce robust quantitative results on the mean differences.

T-Test for Project Cost Growth and Project Schedule Growth

Metrics	Locations	N	Mean	Std. Deviation
costgrow	Alberta	24	.19	.32
	U.S.	153	.02	.15
schdgrow	Alberta	24	.17	.22
	U.S.	151	.03	.15

Independent Samples Test

Metrics		Levene's Test F	Levene's Test Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
costgrow	Equal variances assumed	32.037	.000	4.372	175	.000	.174	.040	.095	.252
	Equal variances not assumed			2.641	24.644	.014	.174	.066	.038	.309
schdgrow	Equal variances assumed	6.191	.014	3.838	173	.000	.136	.035	.066	.206
	Equal variances not assumed			2.921	26.507	.007	.136	.046	.040	.231

Figure 5.18 Statistical Test Outputs for Comparison between Alberta and U.S. - Project Cost and Schedule Growth

The test assumptions for *t*-test were conducted on each metric to ensure that the *t*-test assumptions were met. Since all project data were submitted by different companies, the assumption of data independence is acceptable. A normality test was performed by using Normal Q-Q plots. If the distribution of a given variable is normally distributed, the Q-Q plot will show the data points closely aligned with a straight line at a 45 degree angle. As shown in Figure 5.19, the project cost growth and schedule growth metrics for Alberta and U.S. projects were both considered normally distributed. Although, project schedule growth metric indicated high values on kurtosis (>+3); the *t*-test result is still considered to be robust as long as it does not demonstrate platykurtosis, a flat distribution curve (-3< kurtosis). The detailed results of assumption tests can be seen in Appendix E.2, and metric definitions are provided in Appendix B.

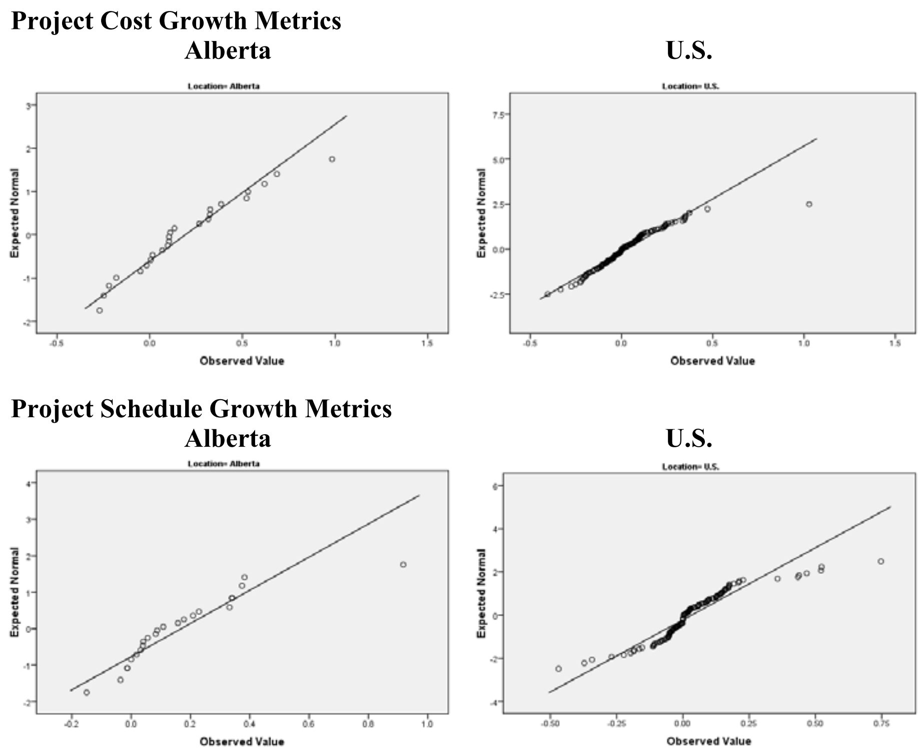


Figure 5.19 Normal Q-Q Plots for Project Cost and Schedule Growth

The test of mean difference for project cost growth and schedule growth between projects in Alberta and the U.S. indicates that result is statistically significant with p=0.014 for cost growth and p=0.01 for schedule growth. The results show statistically significant higher average cost growth and schedule growth for the Alberta projects. This is in line with industry perceptions that Alberta projects are more likely to have significant cost overruns and schedule delays than other typical large EMR projects due to the added burden of challenging environments.

5.4.2.2 Change Cost Factor

Figure 5.20 illustrates the comparison of development change cost factor, scope change cost factor, and total change cost factor for selected Alberta and U.S. projects. The definition of the change cost metrics are provided in Appendix B. In this analysis, the Alberta-based projects may a slightly higher average development change cost factor (0.06) when compared to U.S.-based projects (0.04). In contrast, the average scope change cost factor may be lower than that of U.S. projects. The average total change cost factor was the same for both at 0.06. However, none of these differences were significant (p=0.68 for development change, p=0.25 for scope change, and p=0.95 for total change cost factor). As a result, the comparison of the average change cost factor on Alberta projects and U.S. projects provides inconclusive results at this stage due to small sample size for each change cost factor metric as indicated in Figure 5.20. The differences may be revealed when the sample size become larger.

It was anticipated that the change cost factor, especially development change cost factor would be significantly higher in Alberta projects than U.S. projects. This is because Alberta projects are subjected to super fast tracking and usually executed with a minimal amount of engineering and information. This should lead to a greater amount of changes. Even though none of the change cost factors is statistically significant; it can be seen that the majority of Alberta projects are at the high edge of the data distribution. The average development change cost was skewed by a small number of projects that experienced low development change cost. It is worth mentioning that the results may be affected by the change cost reported by the project teams. Changes were commonly covered by contingency budgets. This indicates that the teams frequently failed to recognize that project cost growth should be driven by and managed through scope and development changes. The tests of assumptions were also examined; the results indicated that all assumption for t-test was satisfied. The detailed results of assumption tests can be seen in Appendix E.2.

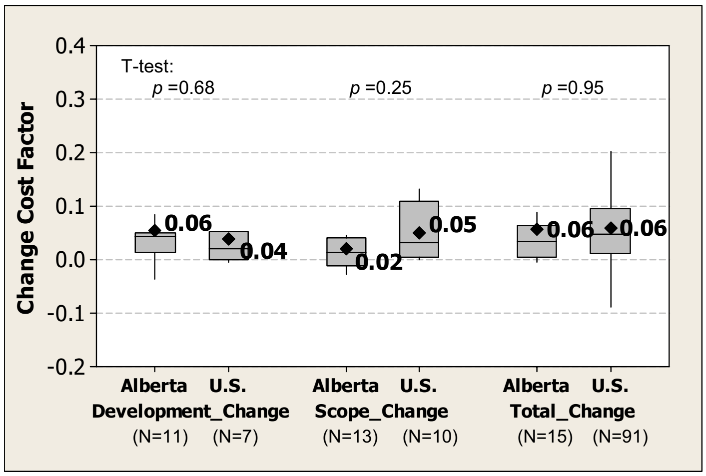


Figure 5.20 Comparison between Alberta and U.S. - Development and Scope Change Cost Factor

5.4.2.3 Rework Factor

Figure 5.21 shows the comparison of work quality between Alberta and U.S. projects in terms of the ratio of the total direct cost of rework to actual construction phase cost. Data analysis is based upon 10 projects in Alberta and 49 U.S. projects. On average, the results indicated that the amount of rework in Alberta projects may be in line with U.S.-based projects with comparable variation. This can be explained by a higher degree of modularization used by Alberta projects to minimize errors. It should be noted that the results should be drawn with caution due to small sample size on Alberta dataset.

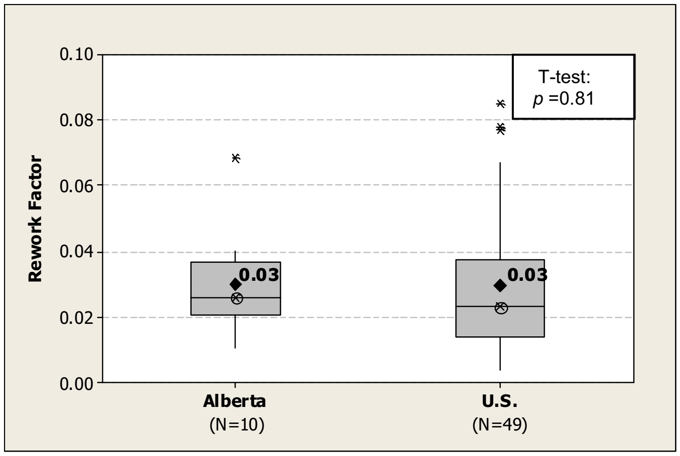


Figure 5.21 Comparison between Alberta and U.S. - Rework Factor

5.4.3 Comparison of Construction Productivity between Alberta and U.S. Projects

The construction productivity comparison between Alberta and U.S. projects was conducted with the purpose of providing quantitative data to justify the industry perception that construction productivity in Alberta projects is as much as three or four times worse that of the U.S. The second purpose is to validate the construction productivity metrics through comparisons. If the comparisons are deemed reasonable, the productivity metrics are confirmed to be reliable measurements. It should be emphasized again that this study defined construction productivity as the ratio of field direct work hours (WH) per actual installed quantity.

Overall, the analysis results are consistent with industry perception. These preliminary results indicate that Alberta projects are less productive with concrete and structural steel work than U.S. projects, while productivity on piping, instrumentation and insulation are comparable. However, these results were drawn based upon the small sample size at this point in the study. The conclusion will be more reliable as the sample size increases. The details of these analyses are presented in subsequent sections.

5.4.3.1 Description of Construction Productivity Dataset

Thirty-three of the 37 Alberta-based projects provided construction productivity data for this research. Many of these projects reported both estimated and actual work hours and quantities. Projects submitted that provided both estimated and actual productivity are presented here. Compared to engineering productivity, construction productivity is considered to be more susceptible to variance due to environmental factors such as weather; therefore the COAA decided from the outset that estimated construction productivity should be tracked to capture these variances.

As shown in Figure 5.22, the symbol ♦ is used to indicate arithmetic mean and the symbol ▲ is used to indicate the median of a particular group. The average project cost of the 33 Alberta projects that assessed construction productivity and submitted data in this study is $460 Million (CDN) after adjustment to July 2007. By contrast, the 32 U.S. large EMR projects with project cost greater than $5 Million (CDN) used from the CII BM&M database have an average project cost of $122 Million (CDN) after time adjustment to July 2007. The U.S. projects with total project cost in excess of $5 Million (CDN) were used to compare construction productivity. This cutoff point was selected based on the CII definition of large projects and to maintain an adequate sample size for analysis. A comparison of project size between these two groups of projects is presented to provide greater understanding of the dataset because the construction productivity may be affected by the differential in average project cost.

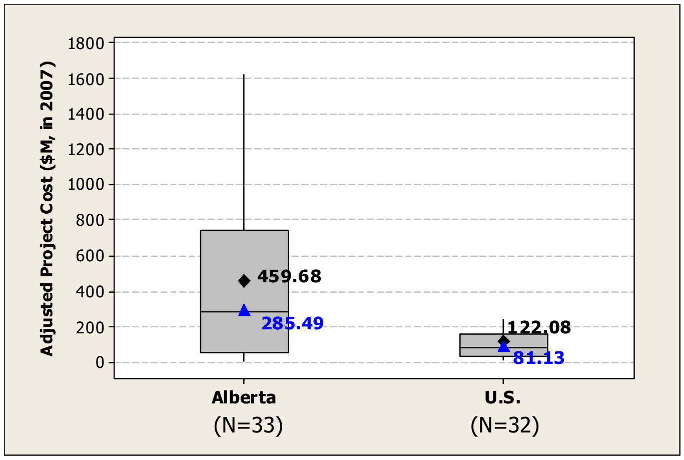


Figure 5.22 Comparison of Project Size ($M CDN, in 2007) for Construction Productivity Dataset

All quantities were converted to the metric system (e.g., linear meter, metric ton) to produce appropriate construction productivity comparisons. Comparisons between Alberta-based and U.S.-based projects are presented by using both arithmetic mean value (indicated by the symbol ♦, and aggregated mean value (represented by the symbol ⊗). Essentially, by adopting CII approach, the aggregated mean creates one large, hypothetical project where total work hours and total installed quantity are assimilated. As found in previous analysis by CII, productivity associated with larger quantities is superior to those with smaller quantities, due to learning curved and economy of size.

T-tests were conducted to compare construction productivity for each work discipline between the Alberta and U.S. datasets as seen in the results provided in Appendix E.2.2. To illustrate the comparison results, the total concrete, total steel, instrumentation, and insulation work disciplines were selected to be presented and discussed in detail in this section. This is due to the fact that these work disciplines were identified by industry experts as major disciplines with relatively large quantities and work hours. Additionally, the data for the three disciplines are sufficient for the comparison with the U.S. dataset. The subsequent sections describe the detailed analyses, including results from assumption tests and *t*-tests, performed on the three disciplines.

5.4.3.2 Total Concrete Construction Productivity

Figure 5.23 provides a comparison of total concrete construction productivity. The preliminary results indicate that U.S.-based projects may place concrete more efficiently than Alberta projects. The U.S. average total concrete productivity rate is 14.44 WH/m^3, compared to 19.39 WH/m^3 for Alberta projects; however, the Alberta dataset is small and this value will continue to change as more data are collected. This difference is not statistically significant (p=0.12), although it approaches the statistically significant threshold (p-value approaches to 0.05). The statistical difference will likely be bridged when a larger sample size is obtained. The initial results are considered to be consistent even given the differences in the size of the projects used for this analysis. Notably, the aggregated mean productivity of U.S.-based projects is 9.72 WH/m^3, compared to 13.10 WH/m^3 for Alberta-based projects.

Overall, the result is in line with the author's expectation. The concrete productivity rate of Alberta projects should be significantly worse with less predictability because the outdoor work is subjected to severe weather. Other disciplines like steel erection or equipment installation are able to maintain better their productivity by building up domes to create workable environments, but this is not usually feasible for concrete work.

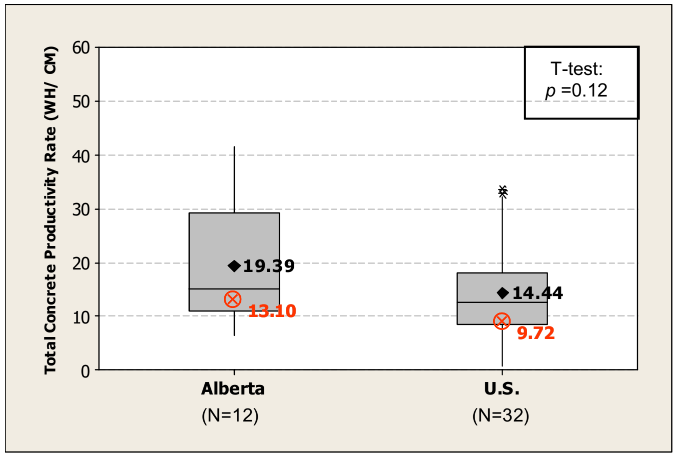


Figure 5.23 Comparison of Total Concrete Construction Productivity (WH/CM)

Similar to the test assumption for project cost growth in Section 5.4.1, Figure 5.24 provides *t*-test outputs from SPSS®. In this analysis, *t*-test was used to evaluate whether the means of total concrete construction productivity between Alberta and U.S. projects are statistically different from each other. As seen in Figure 5.24, the Levene's test indicates that equal variances are assumed for total concrete productivity (p=0.161), thus the p-values for "equal variances assumed" were used as results of *t*-test. This means that the null hypothesis of *t*-test on equal means between two groups was not rejected. It can be concluded that the difference of the average total concrete productivity rate between Alberta and U.S. projects are not statistically significant with p=0.12. It should be noted that the significant results of the mean difference may be affected due to unequal sample sizes between Alberta and U.S. dataset. However, the significant difference (p-value) is approaching 0.05, this may be contributed by the less variance associated in the U.S. dataset which has larger sample size.

T-Test for Total Concrete Construction Productivity

Location		N	Mean	Std. Deviation
Total concrete	Alberta	12	19.394	11.187
	U.S.	32	14.437	8.436

Independent Samples Test

Metrics		Levene's Test		t-test for Equality of Means						
									95% Confidence Interval	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Total concrete	Equal variances assumed	2.034	.161	1.585	42	.120	4.957	3.126	-1.353	11.266
	Equal variances not assumed			1.393	15.935	.183	4.957	3.557	-2.586	12.500

Figure 5.24 Statistical Test Outputs for Comparison between Alberta and U.S. – Total Concrete Construction Productivity

The test assumptions for *t*-test were conducted on the metric to ensure that the *t*-test assumptions were met. Since all project data were submitted by different companies, the assumption of data independence is acceptable. The normality test was performed by using Normal Q-Q plots. As shown in Figure 5.25, total concrete productivity metrics for both Alberta and U.S. projects were skewed but they are considered normally distributed. The detailed results of assumption tests can be seen in Appendix E.2.2, and metric definitions are provided in Appendix B.

Alberta **U.S.**

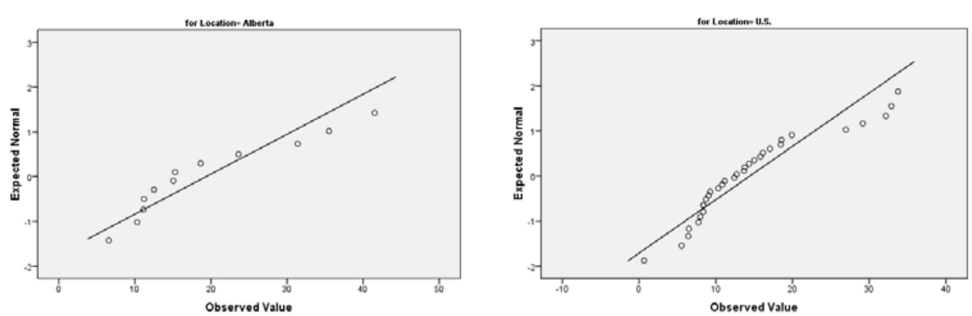


Figure 5.25 Normal Q-Q Plots for Total Concrete Construction Productivity

5.4.3.3 Total Steel Construction Productivity

As seen in Figure 5.26, the U.S.-based projects may be more productive at erecting steel than Alberta projects. Although these results are based on more than 20 Alberta projects, more data are required for significant findings. From the preliminary results as shown in Figure 5.26, better total steel productivity was observed on U.S. projects (53.95 WH/Metric Ton) than Alberta projects (42.41 WH/Metric Ton); however, the differences were not statistically significant (p=0.20). On the other hand, the aggregated average productivity rate of Alberta-based projects is slightly better than that of U.S.-based projects by 1.06%, when considering project size. It should be noted that the results may vary as the sample size increases.

The lower productivity in Alberta can be attributed to the high complexity associated with the larger size of steel structures. In addition, the results show larger variation of total steel productivity for Alberta projects than U.S. projects. This much wider range of distribution on Alberta projects can be explained by the impact of factors such as field fabricated structural steel under extremely cold weather and the degree of modularization used in the projects. The detailed results of assumption tests can be seen in Appendix E.2.2.

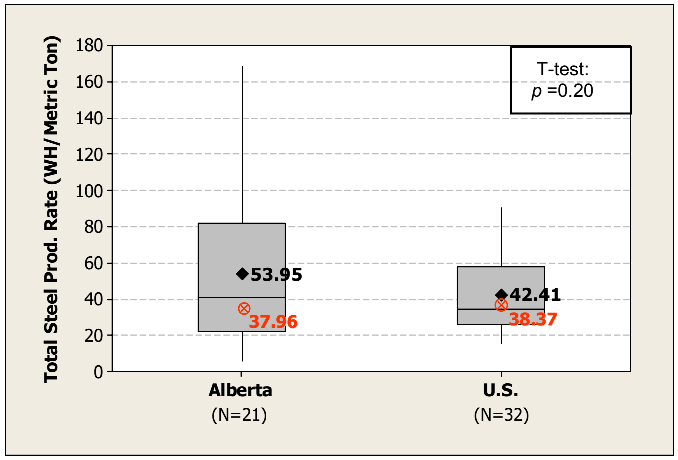


Figure 5.26 Comparison of Total Steel Construction Productivity (WH/Metric Ton)

5.4.3.4 Insulation- Piping Construction Productivity

As can be seen in Figure 5.27, the average rate for piping insulation productivity in Alberta is comparable to U.S.-based projects (1.90 WH/LM versus 1.93 WH/LM, respectively). However, when the aggregated mean calculation is used, Alberta-based projects seem to outperform their U.S.-based counterparts by 35.6%. One hypothesis for this observed difference is that Alberta-based projects likely have much more piping insulation on average, and much of it is pre-installed onto modules. The results suggest the benefits of repetition for this particular construction activity derived from preassembling and modularization. It should be noted that the lack of statistical significance may be attributed to the small sample sizes of both datasets as well as the skewed and wide variations of insulation productivity on the Alberta dataset. Also, with the data available, there is very little observable difference in means. Further analysis with larger sample size is warranted.

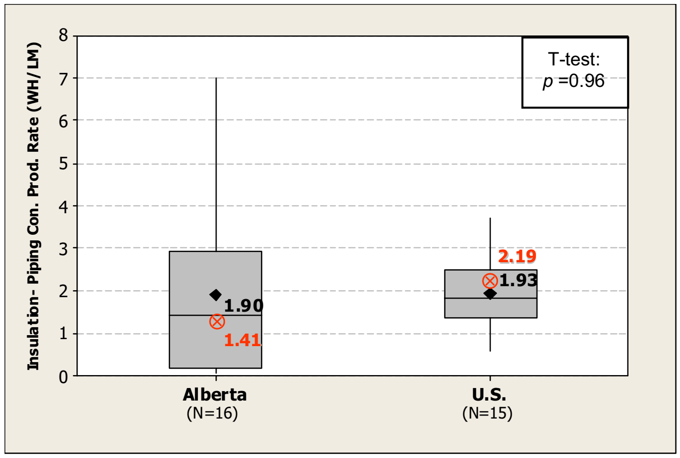


Figure 5.27 Comparison of Insulation- Piping Construction Productivity (WH/LM)

5.4.3.5 Summary of T-test Results for Construction Productivity Comparisons

The same analyses were performed on other construction productivity metrics, yet the results of those metrics cannot be presented due to either small sample size (N<10) or inconclusive results because of wide variation in distributions. The t-test result summary shown in Table 5.4 indicates the mean differences of these remaining construction productivity metrics between Alberta and U.S. projects. Detailed statistics are also provided Appendix E.2.2.

A summary of t-test results conducted on the dataset in this study is shown in Table 5.5. Overall, project data indicated better productivity for U.S. projects on many construction work disciplines. However, Alberta-based projects may be more productive on concrete, piping, and instrumentation installation (as indicated by ✓). Nonetheless, the results do not demonstrate a statistically significant difference for any construction productivity discipline. This may be due to limited data in each dataset and the skewed or sometimes flat distributions of the metrics. A complete list and the detailed analysis of the *t*-test results for all construction productivity metrics are provided in Appendix E.2.2.

Table 5.4 Summary of T-Tests on Construction Productivity between Alberta and U.S. Projects

Construction Productivity Metrics	N		Mean		Alberta is more Productive	*p*-values from T-Test
	Alberta	U.S.	Alberta	U.S.		
CONCRETE:						
Total slab	2	23	9.45	10.62	✓	0.780
Total foundation	3	29	21.30	20.96	-	0.972
Total concrete	12	32	19.39	14.44	-	0.120
STEEL:						
Structural steel	11	22	58.25	42.39	-	0.226
Pipe rack & utility bridge	6	25	50.50	35.24	-	0.237
Miscellaneous steel	9	26	88.10	61.68	-	0.236
Total steel	21	32	53.95	42.41	-	0.256
ELECTRICAL:						
Total electrical equipment	7	18	103.83	57.21	-	0.098
Exposed or above ground conduit	3	25	1.35	1.40	✓	0.890
Total conduit	4	28	1.44	1.20	-	0.496
Cable tray	9	27	2.79	3.14	✓	0.667
Power and control cable	2	23	.35	.29	-	0.842
Total wire and cable	11	22	.51	.32	-	0.220
Electrical-grounding	3	27	27.21	.83	-	0.187
INSTRUMENTATION:						
Instrumentation device	9	22	13.37	13.53	✓	0.973
PIPING:						
Total small bore piping ($\phi \leq 2\frac{1}{2}$")	5	28	6.135	6.70	✓	0.785
Total large bore piping-ISBL ($\phi \geq 3$")	8	27	12.14	13.82	-	0.671
Total large bore piping-OSBL ($\phi \geq 3$")	7	8	8.07	6.76	-	0.659
INSULATION:						
Insulation-piping	16	15	1.90	1.93	✓	0.960
EQUIPMENT:						
Heat transfer equipment	6	25	303.29	461.59	✓	0.696
Rotating equipment	8	30	356.38	623.20	✓	0.696
Atmospheric tanks-shop fabricated	2	15	19.21	98.24	✓	0.119
Power generation equipment	3	11	2418.33	13823.46	✓	0.143
Other process equipment	8	12	508.26	278.92	-	0.442
Modules & Pre-assembled skids	5	10	1095.07	216.35	-	0.326

Note: None of the t-test results shown in the table above is statistically significant
Shaded cells indicate metrics with detail discussions presented in Section 5.5.3

5.4.4 Analysis of Estimating Accuracy of Construction Productivity and Total Installed Unit Cost of Alberta Projects

The following sections evaluate new metrics developed specifically for Alberta projects, including estimating accuracy of field productivity, and total installed unit cost measured by work disciplines. It was believed by Alberta experts that estimating inefficiency is a key reason for significant cost overrun. Estimating better productivity than the actual productivity (overestimation of productivity) significantly impacts project cost and schedule; therefore, data analysis to explore estimating accuracy is needed.

As described in Section 4.1.4, the metrics to measure estimating accuracy are expressed in terms of actual value divided by estimated value. The data shown in the following section is for Alberta only, because the CII BM&M does not track productivity estimates. Because this was the first round of data collection, project data to produce these metrics was minimal. An early look at the distributions of these metrics is still valuable, however.

5.4.4.1 Estimating Accuracy of Construction Productivity on Alberta Projects

Figure 5.28 provides a preliminary assessment of the accuracy of field productivity estimates for three crafts: concrete, structural steel, and piping. This research provides preliminary indication that Alberta project teams tend to significantly overestimate construction productivity (estimate better productivity than actually achieved). Most of the observed data demonstrate that the worst overestimation was on concrete productivity (71%) as compared to structural steel (22%), and piping (4%), on average. It should be noted that the results for concrete were driven by one project, which exceeded the estimated productivity by 3.7 times due to a large amount of scope changes caused by inadequate scope definition at the time of project sanction. Excluding this project, the average accuracy of concrete productivity estimates was approximately 45%. In general, common reasons for productivity estimating inaccuracy in Alberta projects could be due to fast tracking and the impact of environmental challenges.

The results shown in Figure 5.28 were as expected. Concrete work is exposed to direct impact from severe weather because concrete foundations for example, need to be poured onsite, unlike structural steel or piping, that can often be pre-frebricated and transported in modules for site installation.

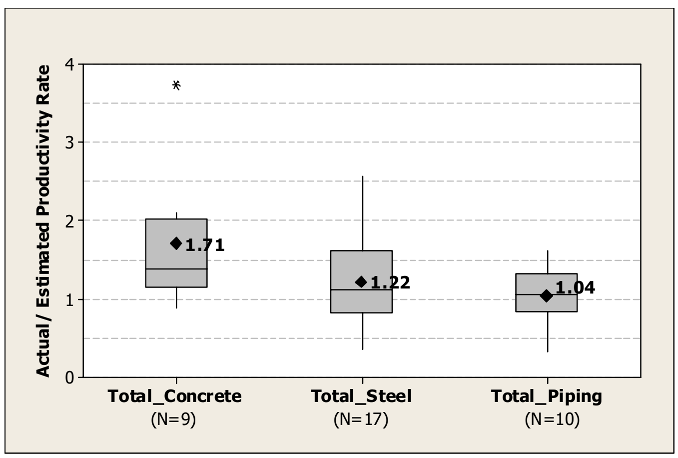


Figure 5.28 Actual/Estimated Construction Productivity Rate by Work Discipline on Alberta Projects

5.4.4.2 Estimating Accuracy of Total Installed Unit Cost (TIUC)

Figure 5.29 provides a preliminary assessment of the accuracy of unit cost estimates for each craft. In this study, TIUC is defined as the burdened cost of direct labor, bulk material, final asset equipment, and civil and sitework equipment by pro rata share, including overhead and profit from both direct hire and subcontract. The detailed definition of TIUC can be seen in the Alberta benchmarking questionnaire in Appendix G.

Consistent with the results for field productivity, these data analysis indicate that Alberta-based projects may better estimate installed piping unit cost, than structural steel and concrete. TIUC were underestimated on average by 2%, 11%, and 34%, respectively. Due to the small sample size used in this study, the average values will likely change as the sample size increases. Again, it can be seen that the piping appears to be one of the most productive work areas in Alberta. Due to the fact that piping work is a major component in Alberta projects, those project teams tend to have high skillset at establishing the estimates. Similar to productivity estimates, the poor accuracy of concrete estimate was driven by one project, which exceeded estimates by 3.5 times. Excluding this project, the average was around 10%.

Some of the deviation in unit cost estimate can be explained by the corresponding underestimation of productivity discussed in the previous section, while higher material cost or development changes could also be contributing factors. In some cases, additional unexpected field installation for pre-assembled modules is needed or inadequate scope definition at the time of project sanction did not identify work to be done. Again, concrete work, which is heavily impacted by weather conditions, was the discipline with the least accurate installed unit cost estimates, which suggests that estimating accuracy suffered could be due to the harsh weather endured on Alberta projects.

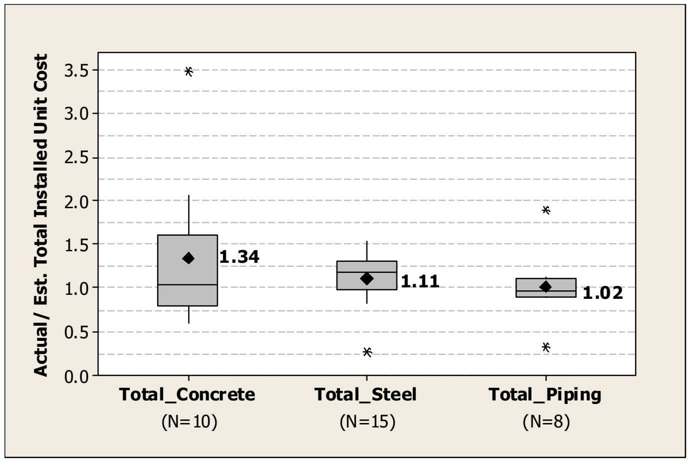


Figure 5.29 Actual/Estimated Total Installed Unit Cost (TIUC) by Work Discipline

5.4.5 Comparison of Engineering Productivity between Alberta and U.S. Projects

With limited Alberta project data, the comparison results on engineering productivity between Alberta and U.S. projects are mixed at this point. The preliminary analysis results indicate that the engineering productivity of total concrete, total piping, electrical and equipment may be similar for both locations, while engineering productivity of total steel appears to be statistically different and less productive in Alberta. However, more data collection is needed to achieve robust results. It is the author’s opinion that with increased data size, differences in the metrics between Alberta and U.S. projects will become more apparent. The detail analyses of engineering comparison are presented in the following sections.

5.4.5.1 Description of Engineering Productivity Dataset

In this comparison, twenty-three of the 37 Alberta-based projects submitted for this research provided measures of engineering productivity. Of these 23 projects, their average project cost was $367 Million (CDN). All costs were normalized to July 2007. As shown in Figure 5.30, the CII BM&M database has 57 large EMR projects that also reported engineering productivity data. The 57 U.S. projects have an average cost of $90 Million (CDN). Due to the CII definition on large projects applied in this study, projects with total project cost greater than $5 Million (CDN) were used for the engineering productivity comparison. As previously described, the differential in average project cost may impact the direct measures of engineering productivity reported here. Therefore, the comparison of project size between these two groups of projects is presented to provide greater understanding of the dataset.

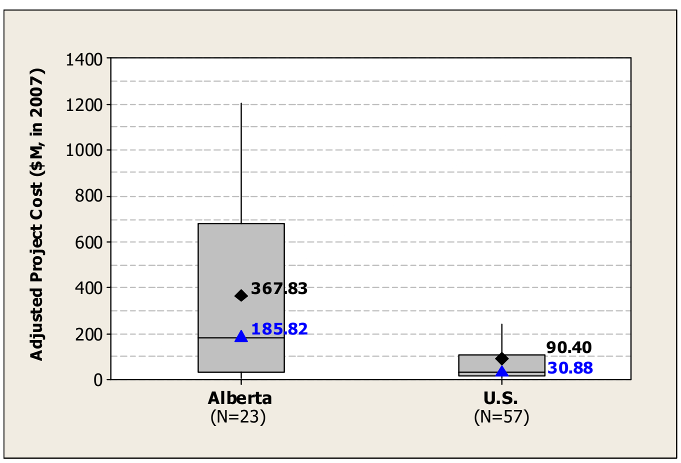


Figure 5.30 Comparison of Project Size ($M CDN, in 2007 Dollars) for Engineering Productivity Dataset

Similar to the construction productivity comparisons, all productivity data units of measure were converted to the metric system (e.g. linear meter, metric ton).

As discussed in Section 3.2, this study adopted the CII BM&M engineering productivity metrics which are measured in direct engineering work hours (WH) per issued for construction (IFC) quantities, for a specific work discipline. Comparisons between Alberta-based and U.S.-based projects are presented by using both the arithmetic mean value (indicated by the symbol♦, and aggregated mean value (represented by the symbol ⊗). For engineering productivity, the aggregated mean is the productivity rate calculated from the aggregated work hours of every project within groups divided by aggregated quantities.

For a comparison of engineering productivity between the Alberta and U.S. dataset, the concrete, structural steel and piping work disciplines were selected to be presented and discussed in detail. Since these major work disciplines are characterized by large quantities and work hours, as well as large sample sizes, a comparison with the U.S. dataset is possible. The subsequent sections describe the three work disciplines along with the assumption test and *t*-test analysis results.

Prior to conducting *t*-test procedures for engineering productivity metrics were examined to ensure that the *t*-test assumptions were plausible. As before, all of the project data were submitted by different companies, the assumption of data independence is acceptable. Inspection of the data by conducting normal Q-Q plots indicates that the metrics are acceptable normally distributed. Moreover, the data distribution of structural steel and piping productivity metrics demonstrate platykurtosis, flat distributions which might reduce the power of significance of the *t*-test. Detailed analysis of the assumption test on engineering productivity metrics are provided in Appendix E.2.3.

5.4.5.2 Total Concrete Engineering Productivity

Figure 5.31 illustrates the preliminary analysis results to assess the differences between concrete engineering on Alberta and U.S. EMR projects. The results suggest comparable concrete engineering productivity when considering mean values (5.92 compared to 4.52 WH/Cubic Meter (CM)), but the result is not significant (*p*=0.46). However, after considering the project size, the aggregated concrete engineering productivity rate on Alberta projects appears to be better than that of U.S. projects (3.53 compared to 6.26 WH/CM). The author expects that concrete engineering productivity should not be significantly different from U.S. projects because most of the engineering designs were done by U.S. based offices. As more data are collected, this expectation may be confirmed.

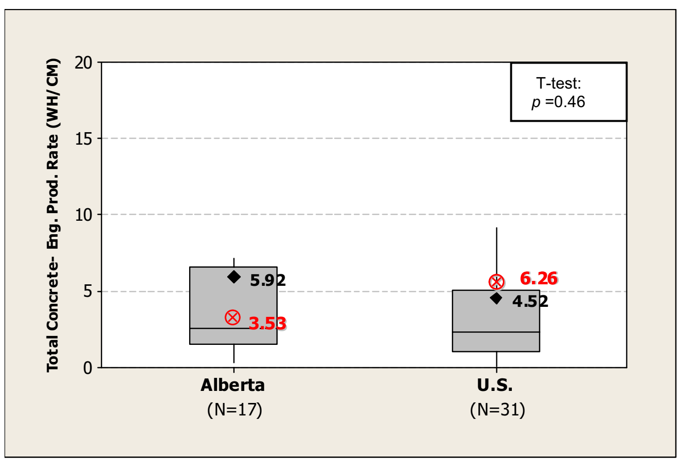


Figure 5.31 Comparison of Concrete Engineering Productivity (WH/CM)

5.4.5.3 Total Steel Engineering Productivity[3]

Figure 5.32 shows a comparison of total steel engineering productivity metrics. The result indicates that average engineering of total steel for U.S. projects is much better than Alberta projects (10.96 WH/MT versus 23.08 WH/MT). This difference is statistically significant different with *p*=0.02; however, the sample size is small. The aggregated average productivity rate of U.S. projects is also better (5.86 WH/Metric ton versus 12.64 WH/Metric ton). The cause of this difference may be due to the greater use of prefabrication and structural steel modules in Alberta which require more hours spent on complex design. Although the results are statistically significant, due to the small sample size, caution is warranted concerning the significance of the findings.

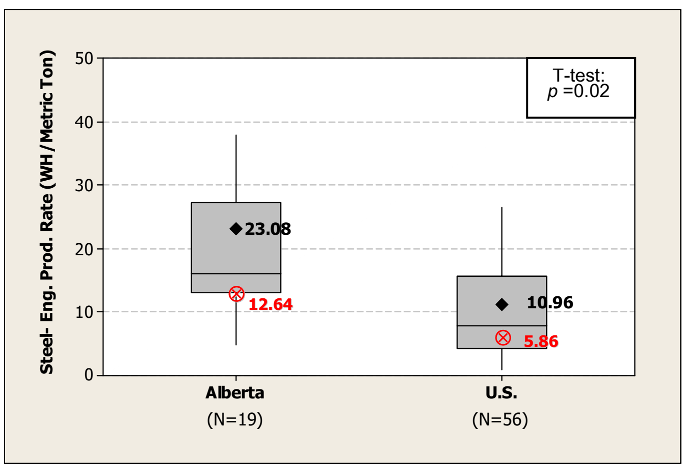


Figure 5.32 Comparison of Total Steel Engineering Productivity (WH/MT)

[3] Total Steel includes structural steel, pipe racks and utility bridges, and miscellaneous steel.

5.4.5.4 Total Piping Engineering Productivity

Figure 5.33 shows a comparison of total piping engineering productivity. Total piping engineering productivity represents combined productivity of small bore and large bore productivity. It is a ratio of the aggregated work hours to aggregated quantity of small and large bore. The preliminary analysis results from this study indicate better productivity in total piping engineering for Alberta-based projects than those of the U.S. (1.60 WH /Linear Meter (LM) compared to 1.97 WH /LM). However, the Alberta dataset is still relatively small and the results do not indicate a statistical difference (p=0.356). In addition, the rates are very similar when considering project size (1.28 WH /LM compared to 1.23 WH /LM). As a result, more project data collection efforts are recommended to achieve more reliable results.

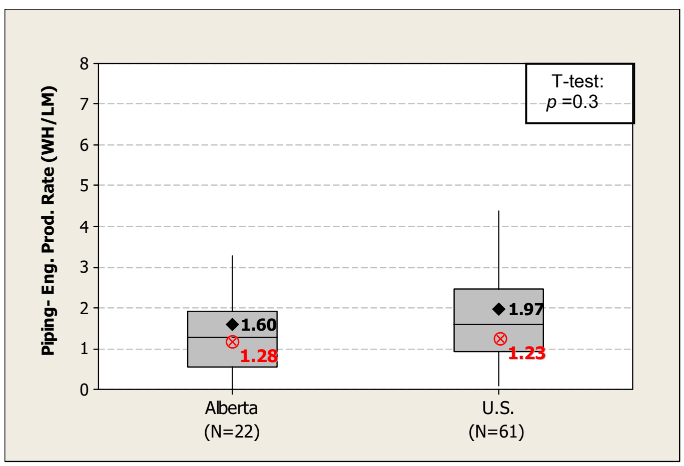


Figure 5.33 Comparison of Piping Engineering Productivity (WH/LM)

The same analyses were performed on other engineering disciplines, yet the results of those metrics cannot be presented due to either small sample sizes (N<10) or inconclusive results due to large variance. The t-test result summary indicating the differences in means of these remaining engineering productivity metrics between Alberta and U.S. projects are summarized in Table 5.5, and detailed statistics are provided in Appendix E.2.3.

Table 5.5 Summary of T-Tests on Engineering Productivity Metrics between Alberta and U.S. Projects

Engineering Productivity Metrics	N		Mean		Alberta is more productive	p-values from T-Test
	Alberta	U.S.	Alberta	U.S.		
CONCRETE:						
Total slab	8	16	2.094	3.042	✓	0.582
Total foundation	10	20	2.770	3.234	✓	0.787
Piling	4	11	2.517	2.393		0.960
Concrete structure	6	13	2.544	3.234	✓	0.660
Total concrete	17	31	5.917	4.525	-	0.463
STEEL:						
Structural steel	9	31	11.102	8.157	-	0.428
Pipe rack& utility bridges	8	10	18.412	8.810	-	0.067
Total structural steel, pipe rack & utility bridge	10	36	17.692	8.879	-	0.037*
Miscellaneous steel	11	29	36.149	11.823	-	0.008*
Total steel	19	56	23.082	10.961	-	0.020*
PIPING:						
Small bore piping ($\phi \leq 2½$”)	10	23	1.004	2.075	✓	0.063
Large bore piping ($\phi \geq 3$”)	12	26	.878	2.577	✓	0.012*
Total piping	22	61	1.597	1.974	✓	0.356
Piping-Hanger and support	8	16	23.566	2.416	-	0.120
ELECTRICAL:						
Total electrical equipment	10	19	67.210	19.325	-	0.074
Conduit	9	18	.709	.482	-	0.397
Cable tray	10	22	.549	1.723	✓	0.012*
EQUIPMENT:						
Pressure vessel	9	14	117.011	138.595	✓	0.759
Atmospheric tank	6	10	228.731	112.253	-	0.286
Heat transfer equipment	8	13	70.446	66.065	-	0.882
Boil and fire heater	5	12	242.044	449.859	✓	0.327
Rotating equipment	8	13	87.323	113.452	✓	0.158
Other process equipment	5	3	187.222	465.733	✓	0.564
Vendor modules & preassembled skids	9	11	217.362	157.131	-	0.275
Total equipment	17	36	152.305	191.863	✓	0.500
INSTRUMENTATION:						
Loop-Instrumentation	18	29	31.585	117.024	✓	0.424
Device-Instrumentation	20	54	15.449	11.309	-	0.207
I/O-Instrumentation	17	44	18.864	9.195	-	0.035*

Note: * indicate statistically significant *t*-test at α level of 0.05
Shaded cells indicate metrics with detail discussions presented in Section 5.5.2

5.4.5.5 Summary of T-Test Results on Engineering Productivity

As shown in Table 5.4, the engineering productivity analysis results are mixed. The findings indicate statistically significant better productivity on Alberta projects in large bore piping, and cable tray. Also, better productivity was observed but not significant for total slab, foundation, concrete structure, small bore piping, total piping, pressure vessels, boil and fire heaters, rotating equipment, power generation, total equipment, and instrumentation- loop. In contrast, the results indicate that U.S. projects have statistically significant better productivity for engineering productivity on combined structural steel/pipe racks & utility bridges, miscellaneous steel, total steel, and I/O instrumentation. However, the results should be evaluated with caution due to limited data in some disciplines. More details are provided in Appendix E.2.3.

5.5 CHAPTER SUMMARY

Most of the projects collected through the Alberta benchmarking effort are grassroots projects with an average project cost greater than $300M (CDN). Cost reimbursable contracts are commonly used to fast track the projects. Due to the remoteness of the jobsites and the extreme weather in Alberta, a high percentage of modularization is typically applied. Because of these conditions, a comparatively high indirect cost and work hours is common. The analysis results show relatively similar scope and development changes for Alberta projects and those projects executed in the U.S. However, the conclusion should be taken with caution because of the small sample size and the fact that Alberta project teams tend to use cost reimbursable contracts and previous CII research indicate that project with reimbursable contracts may underreport costs of changes. This issue was revealed by noting the average 6% change cost factor, which is inconsistent with typically observed 19% average project cost growth.

The comparison of Alberta projects to U.S. projects was done to highlight the differences in project outcomes, and to demonstrate how the challenging environments and other constraints affect performance and productivity. It is imperative to note that this research measures productivity as a ratio of direct work hours to IFC (issued for construction) quantities for engineering and installed quantities for construction. The comparisons show that Alberta projects may have comparable engineering productivity, but they may be less productive with regards to construction compared to U.S. projects in terms of work hours per installed quantity. The analysis results of construction productivity based on this dataset indicate Alberta projects are 1.5 times less productive with concrete and structural steel work than U.S. projects, while productivity on piping, instrumentation and insulation are comparable. These results are consistent with industry perception; however, the experts believe that Alberta's construction productivity could be as bad as 3 to 4 times worse than U.S. projects. As a result, further research was recommended to use cost (all-in labor rate including accommodation, travel, incentives, etc.) per unit quantity for construction productivity comparison due to the higher cost associated to workers in Alberta than in U.S.

According to the limited dataset in this study, Alberta-based projects experience significant project controls issues with higher cost and schedule growth than U.S. projects. Average project cost growth and schedule growth was 19% and 17% for Alberta projects in contrast to 3% for both cost and schedule growth in the U.S. Alberta projects exhibited a wide variation in cost and schedule performance, which indicates that the performance in Alberta may be less predictable due to a high degree of uncertainties. The statistically significant cost and schedule overruns on Alberta projects can be explained to some degree by less productive field workers, a less accurate estimate of peak work force size, indirect costs, construction productivity rates, and unit cost.

The analysis results presented in this chapter bolsters the first hypothesis statement whose purpose is to evaluate the utility of the metrics. Norms and distributions were produced for construction indirect cost and work hour metrics, as well as metrics for the accuracy of productivity and unit cost estimates, among others. These metrics and their norms were validated as understandable and quantifiable measurements through meetings with industry experts, governmental professionals, and academic representatives who participated in this study. As proposed in the first hypothesis, the quantifiable nature of the metrics was also verified through numerical comparisons with U.S. projects.

The comparison results prove the validity of the metric norms and distributions and verify that the Alberta data are not only reliable project performance measurements, but they also provide valuable comparisons against an external dataset (CII). Therefore, it can be concluded that the developed metrics tailored to Alberta challenges are reliable, and comprehensible, meeting the objective of this research.

CHAPTER 6:

ANALYSIS OF PROJECT PERFORMANCE BY PROJECT CHARACTERISTICS, AND MANAGEMENT/ BEST PRACTICES

The purpose of this chapter is to explore the relationship between Alberta project performance and observed project characteristics, project execution strategies and degree of implementation of best practices. The analysis was performed on the Alberta benchmarking dataset. The analysis results validated the longtime beliefs of industry experts regarding which factors are predominantly behind low performance and productivity on Alberta-based projects. The results also yield best practices to improve project outcomes. It should be noted that the trends or relationships presented in this chapter are not intended to demonstrate best fit prediction due to the limited number of data.

By reviewing the relationships between project performance, project characteristics, and management/ best practices, the first hypothesis can be established. This is done by confirming the inferential ability of the specific metrics developed in this study as the next step in the analysis of hypothesis 1, as shown in Figure 6.1.

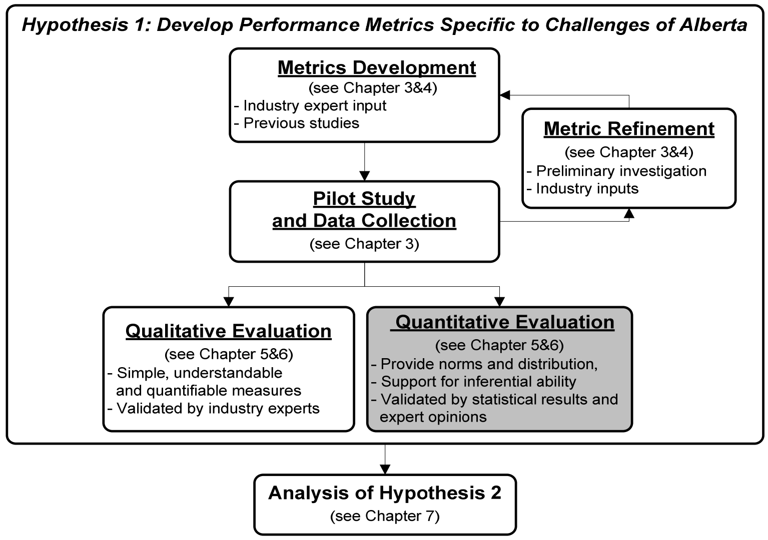


Figure 6.1 Steps for Analysis of Hypothesis 1

6.1 ANALYSIS OF PROJECT PERFORMANCE AND PRODUCTIVITY BY CHARACTERISTICS AND EXECUTION STRATEGIES

The analysis in this section was conducted on the Alberta benchmarking dataset. The analysis consisted of three steps: 1) conducting Pearson's correlations on all potential factors of impact; 2) narrowing the results to include only statistically significant and strong relationships between factors and the performance metrics, and 3) conducting simple regression on all statistically significant factors. The factors presented in detail below have statistically significant and strong relationships with performance metrics and have been identified as highly influential factors according to Alberta industry professionals. In addition to the factors discussed in detail in this section, there are additional factors with statistically significant and strong relationships summarized in Section 6.3

6.1.1 Relationships between Project Performance and Execution Strategies

Based on the analysis described above, the selected factors include *estimating accuracy of workforce predictability*, *percent engineering completed before construction start*, *construction indirect work hours*, and *project size*. These four factors were analyzed with respect to three project performance metrics: project cost growth, schedule growth and construction productivity. After analyzing the factors under the Pearson's correlation, simple regression was conducted to determine how variation in each factor affects project cost, schedule performance and construction productivity by providing the coefficient of determination (R^2). In addition, F and t statistics were produced to verify the statistical significance of the simple regression results at α=0.05. Detailed statistical analysis results and the associated assumption tests are provided in Appendix E.3. Due to a limited amount of data, it should be noted that the trends or relationships presented in this section are not intended for forecasting purposes.

6.1.1.1 Estimating Accuracy of Workforce Predictability

Figures 6.2 and 6.3 illustrate the relationships between *estimating accuracy of workforce predictability at construction peak* and project cost growth and schedule growth, respectively. As described in Chapter 4, the accuracy metric for predicting work force size at construction peak refers to the ratio of the actual number of workers on site at construction peak compared to the estimate. A value approaching 1 indicates high estimation accuracy. The industry perception is that the higher the accuracy of the estimated number of workers on site during construction peak (the metric value close to 1), the lower the project cost growth and schedule growth. Analyses were conducted to examine how a deviation in estimated construction workforce peak numbers affect project cost and schedule performance.

The scatter plots show that most project teams insufficiently estimated the number of workers needed at peak construction, which is indicated by the presence of most data points with estimation accuracy of 1 or greater. Alternatively, there are some projects which were sufficiently estimated as indicated by the concentration of data points around 1 or less. The results of regression model indicate that projects with less predictability (i.e. the metric value greater than 1) had worse project cost and schedule growth than the projects with better workforce predictability (i.e. the metric value close to 1). The results indicate a statistically significant regression model with high *R*-squared value (R^2=0.62, p=0.00, N=20) with regards to project cost growth, and a medium *R*-squared value (R^2=0.30, p=0.01, N=21) for project schedule growth. In addition, a conceptual model be developed, low values of *work force predictability* (i.e. higher estimated required work force size than actually needed) can only be correlated with project cost and schedule savings over a certain range. For example, an excessive estimate of work force size would cause high cost overruns due to additional cost from over-manning and schedule delay due to additional unnecessary works.

In sum, the results as seen in Figures 6.2 and 6.3 are as anticipated by the author. The closer the actual peak construction work force size is to the estimated value, the lower the cost growth and schedule growth experienced on the jobsite. The impact of poor estimations on work force size may significantly lead to cost and schedule growth due to recruiting more workers, the additional costs for extra workers, and the associated indirect costs.

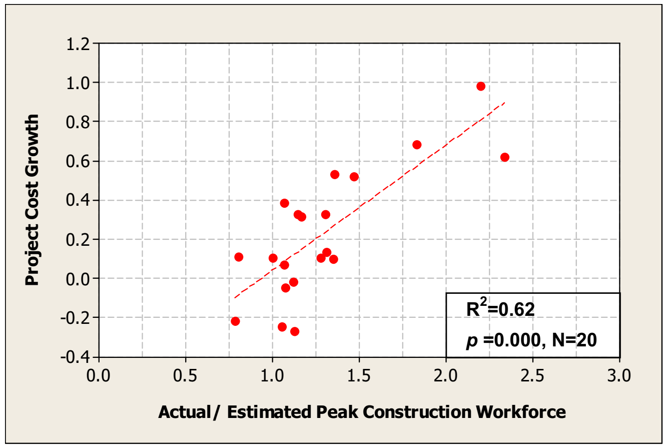


Figure 6.2 Project Cost Growth vs. Estimating Accuracy of Work Force Predictability

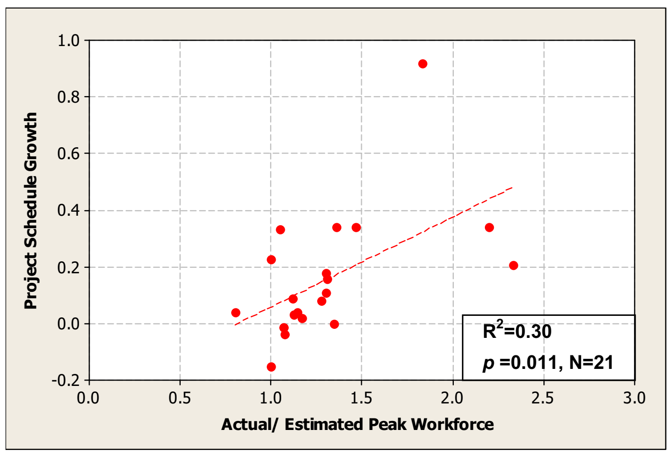


Figure 6.3 Project Schedule Growth vs. Estimating Accuracy of Work Force Predictability

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.787[a]	.620	.599	.209196	1.488

a. Predictors: (Constant), A_E_Peak
b. Dependent Variable: costgrow

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.284	1	1.284	29.342	.000[a]
	Residual	.788	18	.044		
	Total	2.072	19			

a. Predictors: (Constant), A_E_Peak
b. Dependent Variable: costgrow

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.543[a]	.295	.258	.193193	1.606

a. Predictors: (Constant), A_E_Peak
b. Dependent Variable: schdgrow

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.297	1	.297	7.964	.011[a]
	Residual	.709	19	.037		
	Total	1.006	20			

a. Predictors: (Constant), A_E_Peak
b. Dependent Variable: schdgrow

Figure 6.4 Simple Regression Results for Project Cost Growth, Schedule Growth and Estimating Accuracy of Workforce Predictability

The test assumptions for simple regression were conducted on the metrics to ensure that the assumptions were satisfied. Since the project data were submitted by different companies, the assumption of data independence is acceptable. The normality test was performed by using Normal Q-Q plots. As shown in Figure 6.5, the three metrics are acceptably normally distributed. Detailed results from the assumption tests are provided in Appendix E.3.

Project Cost Growth **Project Schedule Growth** **Workforce Predictability**

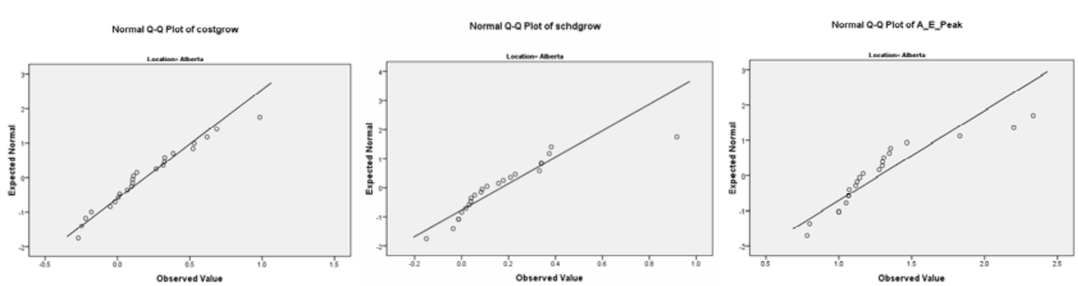


Figure 6.5 Normal Q-Q Plots for Project Cost Growth, Schedule Growth and Estimating Accuracy of Workforce Predictability Metrics

6.1.1.2 Percent Engineering Completed Before Construction Start

Figures 6.6 and 6.7 illustrate the relationships with the simple regression results between project cost growth, schedule growth (specifically during the construction phase) and *percent engineering completed before construction start*, respectively. The *percent engineering completed at construction start* is a milestone metric captured by the benchmarking survey. Generally, it can be anticipated that insufficient engineering at commencement of construction may increase cost and schedule growth, specifically during the construction phase.

The scatter plot as shown in Figure 6.6 indicates that some Alberta projects were fast tracked by starting construction with less than 30% engineering completed before construction start, while others commenced construction at 60% to 90% engineering completeness. With an input from the COAA benchmarking committee, the relationship for construction cost growth displayed in Figures 6.6 uses a cubic polynomial pattern. The statistical results of the cubic polynomial reveal a statistically significant, high *R*-squared value (R^2=0.63, p=0.02, N=14), but the sample size is still small. This regression model implies that as more design is completed before construction start, projects may have less construction cost growth. This holds true until a certain point in engineering completeness where the cost growth curve appears somewhat flat and possibly begins to ascend. As a result, Figure 6.6 suggests that percent engineering completed of 65% to 70% before construction start may lead to better construction cost performance for fast tracked projects. However, the effect on construction schedule growth, as shown in Figure 6.7 is unclear. This early analyses suggests virtually no relationship between percent engineering completeness and construction schedule growth. The assumption tests and detailed analysis of regression results are provided in Appendix E.3.

This fast tracking and cost growth relationship is consistent with COAA benchmarking committee expectations as well as other studies completed by CII and other industry forums. When the *percent of engineering completed before construction start* is inadequate, additional costs are often incurred. Costs that likely result from inadequate construction drawings include change orders, costs relating to unused rental equipment, and wasted time spent by the work force in requesting information from the design team. A similar analysis should be conducted with a larger dataset to clarify this relationship and provide more conclusive results. Again, predictability is not inferred nor concluded in this study due to the small sample size used in the analysis.

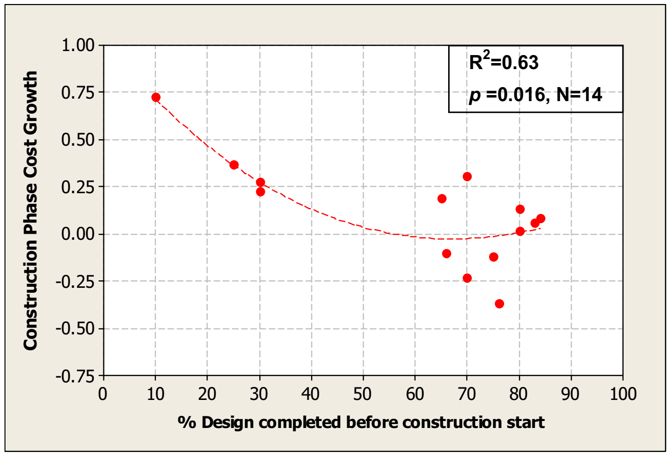


Figure 6.6 Construction Cost Growth vs. Percent Engineering Completed before Construction Start

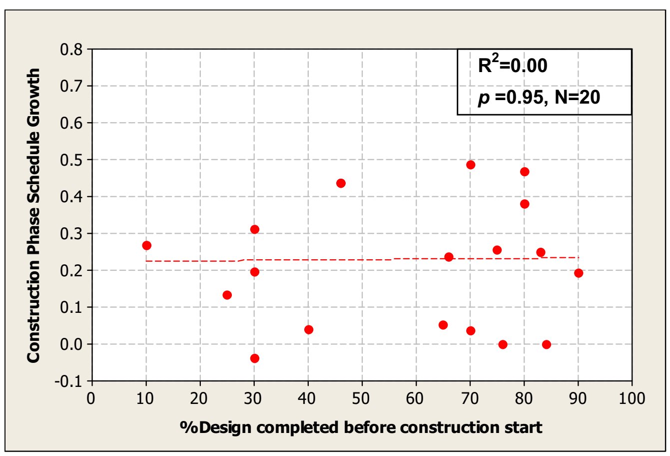


Figure 6.7 Construction Schedule Growth vs. Percent Engineering Completed before Construction Start

6.1.1.3 Construction Indirect Work Hours/Direct Work Hours (%)

Figures 6.8 and 6.9 illustrate the relationships between project cost growth, schedule growth and the amount of *construction indirect work hours* from the simple regression analysis. The *construction indirect work hours* metric is the proportion of indirect work hours to direct work hours, expressed as a percentage. A value greater than one indicates problems relating to work production (i.e. greater work hours attributable to supporting work as opposed to direct work). The industry's assumption on this analysis is that the higher the proportion of indirect work hours to direct work hours, the higher the project cost overruns; however, this may lead to schedule benefits.

It can be seen from the scatter plots that Alberta projects experienced high construction indirect work hours, from approximately 10% to 65% of direct work hours. The regression models shown in Figures 6.8 and 6.9 indicate that projects with a high ratio of *construction indirect work hours* may exhibit better project cost and schedule performance. The results specify that the regression model is not statistically significant with low *R*-squared value (R^2=0.14, p=0.11, N=19) on project cost growth, and (R^2=0.04, p=0.42, N=19) on project schedule growth. It should be noted that if a larger sample size is obtained, it is the author's opinion that this factor may result in a statistically significant relationship with cost growth.

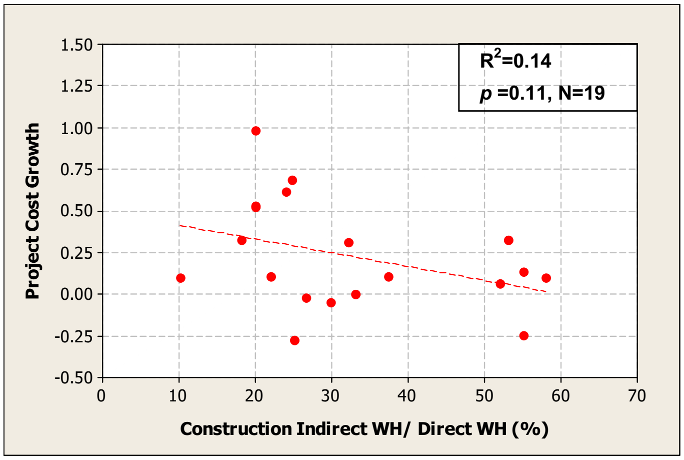


Figure 6.8 Project Cost Growth vs. Construction Indirect Work Hours/ Construction Direct Work Hours (%)

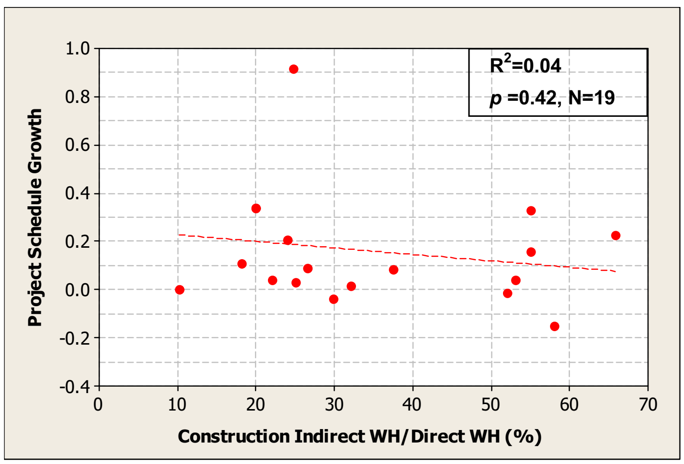


Figure 6.9 Project Schedule Growth vs. Construction Indirect Work Hours/Construction Direct Work Hours (%)

The results of the analysis on the proportion of construction indirect work hours to direct work hours on project cost performance may not be intuitive. It is generally believed that high *construction indirect work hours* lead to high project cost growth due to the costs associated with indirect works, such as mobilization, material handling, and maintenance. However, the results from the simple regression performed in this study indicate that as indirect work hours increase, project cost growth decreases. One explanation is that the greater the indirect work hours, the greater the productivity of the work force on direct work tasks. Also, the higher the indirect work hours to direct work hours, the lower the schedule growth as suggested by Figure 6.9. Again, these analyses are based upon only 19 projects in the dataset.

6.1.2 Analysis of Construction Productivity by Project Characteristics

As discussed in detail in Section 2.2, this study adopted CII's method to evaluate construction productivity at the project level. This method, known currently as the Construction Productivity Project Level index (CPM Index), provides a macro-view of project construction productivity. As a relative productivity performance measure, the CPM index ranges from -3 to 3, with -3 indicating the best observed productivity performance. Here one unit difference in the CPM index is equivalent to a 100% observed difference in productivity.

6.1.2.1 Project Size ($M CDN, in 2007)

Figure 6.10 illustrates the relationships from the simple regression results between construction productivity project level index (CPM index) and project size. Project size is presented as the total project cost in millions of Canadian dollars adjusted to 2007 values. A higher CPM index value indicates lower construction productivity of a project. The experts' expectation is that the larger the project size, the lower the construction productivity (i.e. higher CPM index values). The CPM index is critical to the examination of factors affecting construction productivity because, most of the time, these factors affect all disciplines and not individual disciplines. As seen in Figure 6.10, the project data for Alberta-based projects indicate that larger projects may have better construction productivity than smaller projects. The results of the regression analysis are not statistically significant with a low resulting *R*-squared value (R^2=0.13, *p*=0.12, *N*=20).

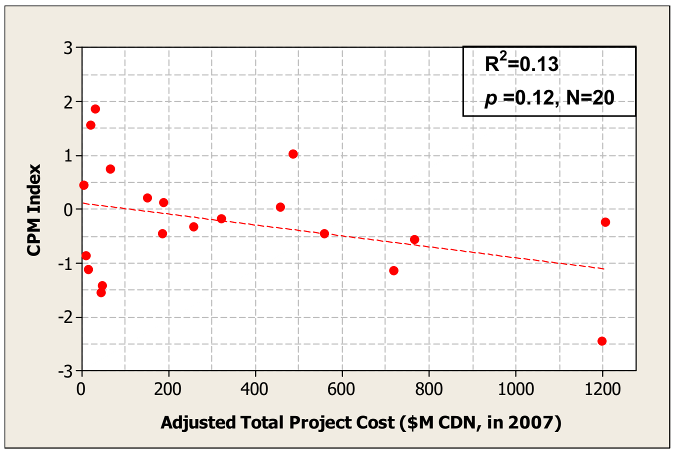


Figure 6.10 Construction Productivity Project Level Index (CPM Index) vs. Project Size ($M CDN, in 2007)

The results of this analysis are in line with the expectations of experts on typical large EMR projects. As indicated from previous analysis by CII, productivity associated with larger quantities is superior to those with smaller quantities. This can be attributed to the repetitive nature of the work and the economy of size. These factors may improve overall construction productivity results. However, the result conflicts with the perception of Alberta industry experts. From their experience, as project size increases, there is worse productivity on site. From their experiences, most previous projects were typically 3 to 4 times less productive than U.S. projects due to the impact of the unique Alberta environment. On the other hand, the COAA benchmarking committee anticipated that the results would be the opposite. It is the committee's opinion that the results obtained in this study are reflective of the high use of modularization typical on large EMR projects. As explained above, direct work hours attributable to large scale installations and a high level of modularization utilization lead to better exhibited construction productivity. However, the idea that larger projects have better construction productivity, as indicated by Figure 6.10, should be made with caution since the CPM index only measures direct construction productivity. It should be noted that the results of this analysis should not be used for estimating or forecasting purposes as more data are needed to draw a statistically robust conclusion.

6.1.2.2 Other Project Executing Strategy Factors

Statistical analysis was also conducted on the impact of other project executing strategy factors on the CPM index. Due to small sample size (N<10), the relationships of these factors are not presented in detail. However, for illustration purposes, the very preliminary analysis of these relationships is briefly discussed in the following section.

Figure 6.11 shows the relationship between CPM index and the percent modularization. The results are graphically represented in a box and whisker plot diagram because the percent modularization factor was collected as discrete data and has a small sample size; thus, linear regression is not appropriate. Even with bin size of 2 to 3, the results show evidence that higher use of modularization may lead to better jobsite productivity. The results align with industry expectations and previous research conducted by Malik (2009) that indicates that modular construction requires only approximately one-third of the duration of field construction. Site installation is minimized when modules are shipped with conduit, light fixtures, and other electrical equipment in place, and do not require field installation. This is greatly advantageous to projects suffering from severe weather and labor shortages. The consistency of results in Figure 6.11 is truly remarkable given the very small sample size; however, caution is again warranted for these preliminary findings.

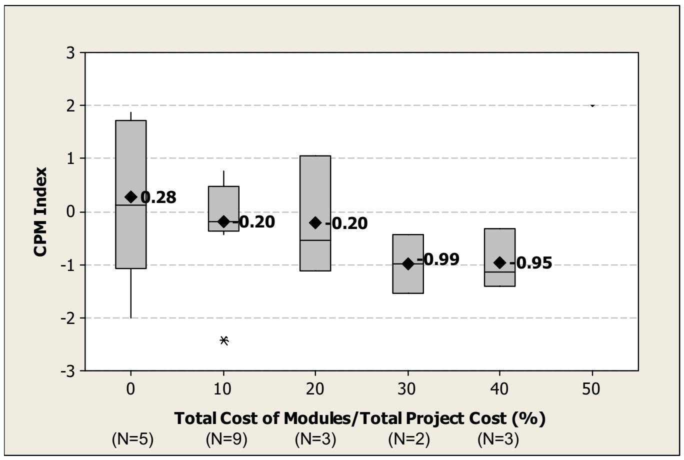


Figure 6.11 CPM Index vs. Percent Modularization

In addition, Figure 6.12 which again is based on very small samples indicates that approximately 11% more productivity occurs when the work force adheres to a 10-4 work schedule rather than a traditional 5-2 work schedule. That is 10 working days (on site) in a row followed by 4 days off work may lead to better onsite productivity than 5 working days with 2 days off. These results will likely become significant with more data. The results also support the widely accepted Alberta project 10-4 work schedule, which corresponds with 10 continuous work days followed by 4 days off work. This work schedule is beneficial in that unproductive works periods are minimized, continuity of work is maintained, and motivation of workers is sustained.

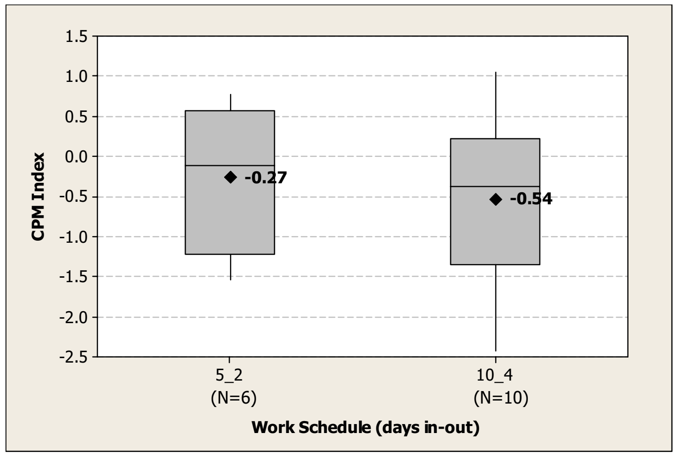


Figure 6.12 CPM Index vs. Work Schedule (days on-off)

Another factor researched was the influence of union versus non-union workers. Based on the dataset in this study, the preliminary results indicate that projects may be approximately 30% more productive with union workers than non-union workers in Alberta. This is consistent with recent studies showing that a unionized work force may better equipped to perform work due to quality training, experience with the latest equipment, and a strong support system. Studies conducted by the United Steelworkers (USW) indicate that union workers are 27% more productive than non-union workers. However, the results of this study are statistically inconclusive based upon the number of data points, thus they are not presented in this section. The author strongly recommends that the data collection effort continues beyond this research so that more robust analyses can be achieved.

6.1.3 Summary of Relationships between Project Performance and Productivity by Project Characteristics and Execution Strategies

In the first part of the analysis of relationship between factors and Alberta project performance, the Pearson's correlation was conducted on all potential factors and Alberta performance metrics. Tables 6.1 and 6.2 present the entire list of project performance metrics and the 10 factors, as well as a summary of the Pearson's correlation results of each factor. A short description of the 10 factors is listed below:

1) Project size ($ Million CDN)
2) Project duration (weeks)
3) Contingency budget (i.e. contingency budget/total project cost in percentage)
4) Percent engineering completed before construction start
5) Percent modularization (i.e. total cost of all modules/total project cost)
6) Percent offsite construction hours (i.e. offsite construction labor hours/total construction hours)
7) Percent construction indirect work hours (i.e. indirect/direct work hours)
8) Percent construction indirect cost (i.e. indirect/direct construction cost)
9) Workforce predictability (i.e. actual/estimated size of peak workforce)
10) Percent scaffolding work hours (i.e. scaffolding work hours/total direct construction work hours)

SPSS was used to perform data analysis in this section. In this study, r<0.3 is defined as low correlation, r between 0.3 and 0.5 indicates moderate correlation, while r≥0.5 signifies high correlation. The nine shaded cells in Tables 6.1 and 6.2 highlight the factors discussed in detail in the previous section.

Table 6.1 Correlations of Alberta-based Project Performance with Project Characteristics

Performance Metric[1]	Project Characteristics									
	Adjusted Total Project Cost ($M CDN)		Total Project Duration (weeks)		Construction Duration (weeks)		% Contingency Budget		% Engineering Completed Before Construction Start	
	N	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*	*r*
COST										
Project Cost Growth	23	0.468*	22	0.017*	21	0.714*	17	-0.591*	19	-0.551*
Project Budget Factor	23	0.499*	22	0.362	21	0.522*	17	-0.456*	19	-0.248
Construction Phase Cost Growth	18	-0.004	17	0.280	16	0.496	16	-0.470*	14	-0.723*
Construction Indirect Cost Growth	17	0.599*	16	0.487	15	0.751*	15	-0.429	14	-0.679*
Startup Cost Growth	9	-0.162	10	-0.211	10	0.070	10	-0.177	8	-0.190
SCHEDULE										
Project Schedule Growth	21	0.031	23	0.122	22	0.096	17	0.029	21	-0.117
Project Schedule Factor	21	-0.056	23	-0.169	22	-0.233	17	0.285	21	-0.105
Construction Phase Schedule Growth	20	-0.059	22	0.201	22	0.195	17	-0.254	20	0.016
Startup Schedule Growth	17	-0.166	18	-0.129	18	-0.067	14	-0.120	16	-0.005
CHANGES										
Total Change Cost Factor	14	0.055	15	0.429	15	0.499	12	-0.360	15	0.358
Development Change Cost Factor	10	0.142	11	0.471	11	0.677*	11	-0.556	10	-0.655*
Scope Change Cost Factor	12	0.148	13	0.497	13	0.460	10	-0.081	12	-0.469
REWORK										
Field Rework Cost Factor	8	-0.174	8	0.411	8	0.083	8	0.394	8	0.418
SAFETY										
Lost time Frequency (LTF)	©	©	8	-0.260	8	-0.482	©	©	©	©
Lost Time Severity (LTS)	17	0.733*	17	0.481	17	0.481	14	-0.447	15	-0.227
PRODUCTIVITY										
Construction Productivity (CPM Index)	20	-0.364	19	-0.161	19	-0.128	15	0.143	17	-0.226

[1] Metric and phase definitions are provided in Appendix A.

© Indicate small sample size (N<8).

r = Pearson correlation; * Indicates statistically significant correlation between factors and performance metrics at alpha level of 0.05.

Shaded cells indicate factors and their scatter plots with regression analyses provided in Sections 6.1 and 6.2.

Table 6.2 Correlations of Alberta-based Project Performance with Project Characteristics (continued)

Performance Metric	Project Characteristics											
	% Modularization		% Offsite Work Hours		% Construction Indirect/Direct WH		% Construction Ind./Dir. Cost		Work force Predictability		% Scaffolding/ Direct WH	
	N	r	N	r	N	r	N	r	N	r	N	r
COST												
Project Cost Growth	22	-0.236	22	-0.119	19	-0.379	17	-0.033	20	0.787*	18	0.362
Project Budget Factor	22	-0.114	22	-0.003	19	-0.353	17	-0.203	20	0.598*	18	0.252
Construction Phase Cost Growth	17	-0.211	17	-0.244	15	-0.307	17	-0.013	15	0.773*	15	0.188
Construction Indirect Cost Growth	16	-0.282	16	-0.413	14	-0.010	17	0.095	14	0.596*	15	0.705*
Startup Cost Growth	10	-0.542	10	-0.271	10	0.537	8	-0.201	10	0.347	9	0.348
SCHEDULE												
Project Schedule Growth	22	-0.362	22	-0.583*	19	-0.194	15	0.055	21	0.543*	17	-0.097
Project Schedule Factor	22	0.081	22	-0.004	19	-0.446*	15	-0.109	21	0.314	17	-0.030
Construction Phase Schedule Growth	21	-0.647*	21	-0.337	19	0.067	14	0.144	21	0.486*	17	0.020
Startup Schedule Growth	18	-0.210	18	-0.425	18	-0.110	11	-0.206	19	0.402	16	-0.050
CHANGES												
Total Change Cost Factor	16	-0.326	16	-0.386	16	0.511*	10	0.356	16	-0.200	15	-0.261
Development Change Cost Factor	11	-0.343	11	-0.530	11	-0.244	10	0.044	11	0.809*	10	0.326
Scope Change Cost Factor	13	-0.279	13	-0.184	13	0.063	8	0.588	13	-0.003	12	0.445
REWORK												
Field Rework Cost Factor	11	0.242	11	0.406	10	-0.013	9	-0.121	10	-0.158	11	-0.347
SAFETY												
Lost time Frequency (LTF)	8	0.629	8	0.672	8	-0.382	©	©	8	-0.387	©	©
Lost Time Severity (LTS)	18	-0.112	18	0.091	18	-0.327	13	0.512	19	0.520*	17	0.171
PRODUCTIVITY												
Construction Productivity (CPM Index)	20	-0.387	20	-0.119	19	0.178	14	-0.093	20	-0.078	18	0.059

6.1.3.1 Summary Results of Pearson's Correlation

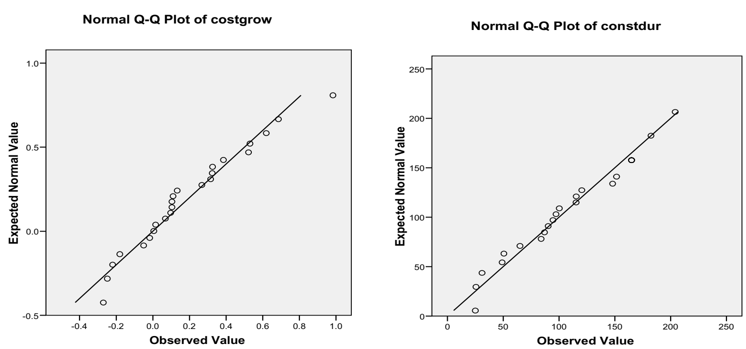
As can be seen from Tables 6.1 and 6.2, the correlation results are mixed. Overall, some factors were correlated as expected by the author. Moreover, there are not many relationships indicating statistically significant correlations. This may be explained by the small sample size at this point in the study. The author believes that analyses on larger sample sizes will provide stronger correlations and also produce more statistically significant relationships. To ensure that the underlying assumptions for Pearson's correlation were accurate, each of the 10 factors and performance metrics were examined. Overall, the assumptions of Pearson's correlation are met. The assumption of independence of each observation is reasonable since project data were submitted by different companies. The assumptions of normality and linear relationships among variables were also accepted.

The following sections provide an overall summary of additional findings on the relationships between major performance metrics and the ten potential factors. The six following performance metrics are highlighted in this section: project cost growth, schedule growth, total change cost factor, rework factor, lost time severity, and CPM index. For illustrative purposes, detailed statistical assumption tests on project cost growth are provided in the following section. The assumption test results for other performance metrics are presented in Appendix E.2.1.

6.1.3.2 Project Cost Growth

The project cost growth metric measures the proportion of actual project cost in excess of the budget. Of the 10 factors examined in this analysis, the factor with the strongest relationship with cost growth was work force predictability as described in detail above. The factor with the second strongest relationships with project cost growth is construction duration (weeks) (r=0.714, p=0.00, N=21). This is in line with the industry expectation that the longer the projects, the higher the cost growth. The test assumptions for Pearson's correlation, as provided in Appendix E.2.1, were conducted on project cost growth and construction duration to ensure that the t-test assumptions were met. As shown in Figure 6.13, both the project cost growth metric and construction duration are considered normally distributed, and the relationship is accepted as linear for Alberta projects. Therefore, the Pearson's correlation result produced is acceptable.

Normal Q-Q Plot of Project Cost Growth and Construction Duration (weeks)



Scatter Plot between Project Cost Growth and Construction Duration (weeks)

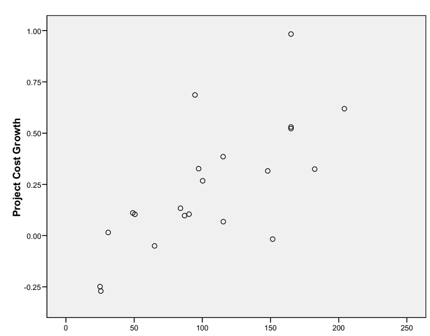


Figure 6.13 Test Assumptions for Relationship between Project Cost Growth and Construction Duration

6.1.3.3 Project Schedule Growth

Project schedule growth measures the proportion of the actual project schedule duration relative to the planned schedule duration. See Appendix B for detailed definitions of metrics. Overall, the results shown in Tables 6.2 and 6.3 do indicate neither statistically significant correlations nor strong relationships between project schedule growth and factors. However, other than work force predictability, as detailed discussion in previous section, the results indicate the higher the percent of offsite work hours, the lower the project schedule growth. This relationship has a high negative statistically significant correlation (r=-0.583, p=0.00, N=22). These results can be explained due to the advantages of increased onsite installation when the offsite modules are used on the projects. This supports the underlying conclusion that the higher the use of modularization or prefabrication, the lower the project schedule growth (i.e. the better the schedule performance).

6.1.3.4 Project Development Changes Cost Factors

The project development change cost factor refers to the costs associated with the change orders that arise due to unforeseen events or conditions. Tables 6.1 and 6.2 indicate statistically significant strong correlations between the project development change cost factor and the following: 1) construction duration (r=0.677, p=0.02, N=15), 2) percent engineering completed before construction start (r=-0.655, p=0.04, N=15), and 3) work force predictability (r=0.809, p=0.03, N=16). The results indicate that the longer the project construction durations, the larger the size of the work force, which may lead to more change orders on a project. This may be due to fast tracking and high complexity, which are characteristics of large projects with long durations. Projects with long durations tend to have early construction execution with less information available, leading to a higher number of development changes on the projects. This is confirmed by the results indicating that the more engineering completed prior to construction start, the lower the total cost of changes orders needed on average on a project.

6.1.3.5 Rework Factor and Safety Performance

The rework factor is defined as the proportion of cost incurred due to rework and the total construction phase cost. The results shown in Tables 6.1 and 6.2 indicate no statistically significant relationship exists between the rework factor and the 10 factors. This may be due to the small dataset. Insufficient project data (N<10) are indicated, as a result, the data were suppressed for confidentiality purposes. However, it is generally believed the analyses with larger sample sizes are expected to yield more significant and perhaps higher correlations between rework factor and the percent engineering completed before construction start. As indicated by previous research studies, the higher the engineering completeness before construction start, the lower the anticipated rework. Moreover, project data indicate a high statistically significant positive correlation between lost time severity (LTS) and project size ($) with r=0.733, p=0.02, and N=17. Projects with longer durations tend to have more severe accidents than shorter projects; however, the findings also are based upon small samples.

6.1.3.6 Construction Productivity Project Level Index (CPM Index)

As described in Chapter 2, Construction Productivity Project Level Index (CPM Index) is an index representing the overall construction productivity of a project. A lower CPM index indicates better construction productivity for a project.

Overall, the results shown in Tables 6.1 and 6.2 indicate no statistically significant relationship between CPM index and each of the 10 factors. This may be due to a small dataset at this point of the study. Analyses with larger sample sizes are expected to indicate significant high correlations between CPM index and the following factors: percent modularization, offsite construction and engineering completed before construction start. The results are supported by industry expert input indicate that larger projects in terms of size tend to use prefabrication modules at higher rates in order to maximize onsite construction productivity.

6.2 Analysis of Project Performance and Best Practices

The purpose of the data analysis in this section is to examine the relationship between project performance and the level of implementation of each best practice. The analyses provide a result to determine which best practices lead to improved Alberta project performance and also confirm the inferential ability of developed metrics in this research study. As described in Section 4.1, 14 best practices question sets measure the level of their implementation. The first 13 best practices were developed by CII to assess the degree of implementation of best practices on typical large construction projects. Benefits of CII best practices have been proven over the years by CII participant companies. The COAA benchmarking committee requested adding Workface Planning, the COAA best practice relating to work packaging to the survey for Alberta benchmarking.

As described in Section 4.1.5, best practice metrics are measured on a scale of 0 to 10, with 0 indicating no implementation and 10 indicating high implementation of a specific best practice. A preliminary inspection of the level of best practices implemented on Alberta projects indicates that most projects in the Alberta dataset have a medium to high level of implementation on each best practice (i.e. each best practice score is between 5 and 10), except front end planning, which was not assessed across all projects studied.

6.2.1 Relationships between Project Performance and Best Practices

This section presents detailed analysis on the relationship between project performance and best practices as follows: 1) project cost growth vs. automation/integration technology (AI Tech), 2) project cost growth vs. project risk assessment (PRA), 3) project schedule growth vs. constructability, and 4) construction phase schedule growth vs. material management. These selected metrics are the ones that resulted in statistically significant relationships based on simple regression. Furthermore, the relationships between these selected metrics and best practices are of interest to Alberta industry professionals. The simple regression results along with the associated test assumptions for each best practice on each project performance metric are presented. Detailed statistical analysis results and tests of associated assumptions are provided in Appendix E.4. Due to the limited number of project data, it should be noted that the trends or relationships presented in this section are not intended for prediction purposes. In addition to the best practices discussed in this section, there are further results with statistically significant and strong relationships summarized in Section 6.5.

6.2.1.1 Automation/Integration Technology (AI Tech)

Figure 6.14 illustrates the relationship with the simple regression results between project cost growth and the degree of implementation of Automation/Integration Technology (AI Tech). AI Tech refers to a practice addressing the degree of use of automation use and the integration of information systems for work functions (CII, 1999). The author hypothesizes that the higher the degree of AI technology use on Alberta projects, the lower the project cost growth. It is anticipated that the high costs associated with using AI technology will be justified by the realized benefits, including those relating to 3D/4D drawings, integrated work process among project participants, automated material inventory, and material installation accuracy.

As shown in Figure 6.14, the results indicate that higher use of AI technology use may lead to better project cost performance (i.e. lower project cost growth). These results are statistically significant with medium *R*-squared value despite the relatively small sample size (R^2=0.38, p=0.01, N=20). The statistical results are presented in Figure 6.15. However, the result of implementing AI is not statistically significant with regard to project schedule performance. The results are consistent with the author's expectation. Technology can be leveraged to save on project cost by streamlining construction activities and maintaining a high level of accuracy on the jobsite.

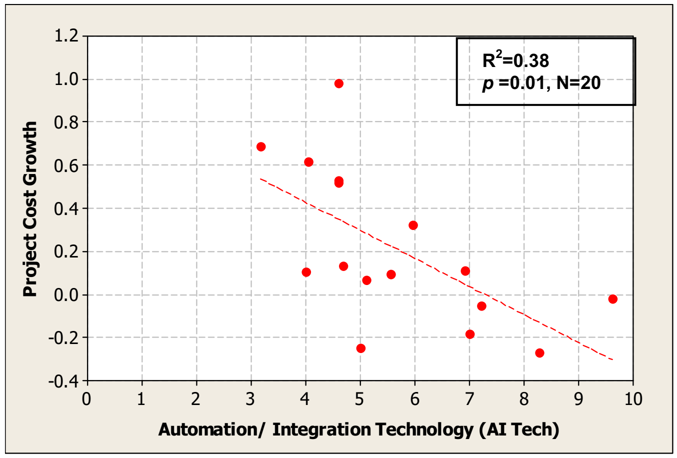


Figure 6.14 AI Technology vs. Project Cost Growth

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.617[a]	.381	.346	.264863	1.640

a. Predictors: (Constant), aitech

b. Dependent Variable: costgrow

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.776	1	.776	11.056	.004[a]
	Residual	1.263	18	.070		
	Total	2.038	19			

a. Predictors: (Constant), aitech

b. Dependent Variable: costgrow

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.941	.223		4.226	.001
	aitech	-.129	.039	-.617	-3.325	.004

a. Dependent Variable: costgrow

Figure 6.15 Simple Regression Results for Project Cost Growth and AI Tech

The test assumptions for simple regression were conducted on the metrics to ensure that the assumptions were met. Since all project data were submitted by different companies, the assumption of data independence is reasonable. The normality test was performed by using Normal Q-Q plots. As shown in Figure 6.16, the metrics are approaching normal distribution. Therefore, the simple regression results are considered robust. Detailed results of assumption tests and simple regression results are provided in Appendix E.4.

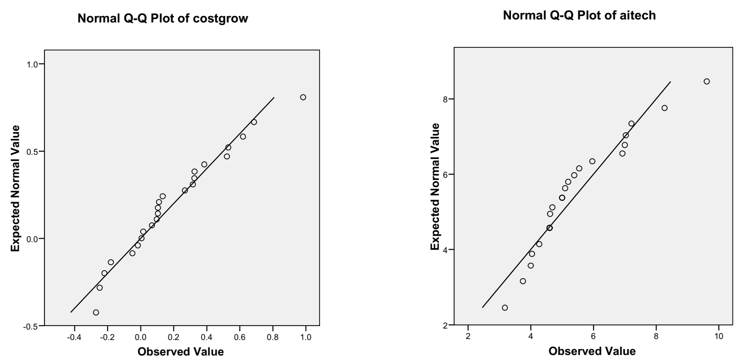


Figure 6.16 Project Cost Growth vs. AI Tech

6.2.1.2 Project Risk Assessment (PRA)

As defined by CII, Project Risk Assessment (PRA) is the process used to identify, assess and manage risk. A project team is designated to evaluate risk exposure for potential project impacts and to provide focus for mitigation strategies. It was the author's expectation that the higher the implementation of PRA, the lower the project cost growth. As shown in Figure 6.17, the preliminary analysis results show a negative slope trend line indicating that more focused implementation of PRA may lead to better project cost performance. The results indicate a statistically significant regression model with medium *R*-squared value (R^2=0.19, p=0.05, N=21). However, the results are not shown for schedule performance because they indicate low correlation between PRA implementation and project schedule growth. Overall, the results of the PRA analysis are in line with the author's initial expectations that the higher the implementation of PRA would improve cost growth.

Alberta projects are characterized by significant challenges and risks, and thus, better risk assessment (PRA) means better project controls overall.

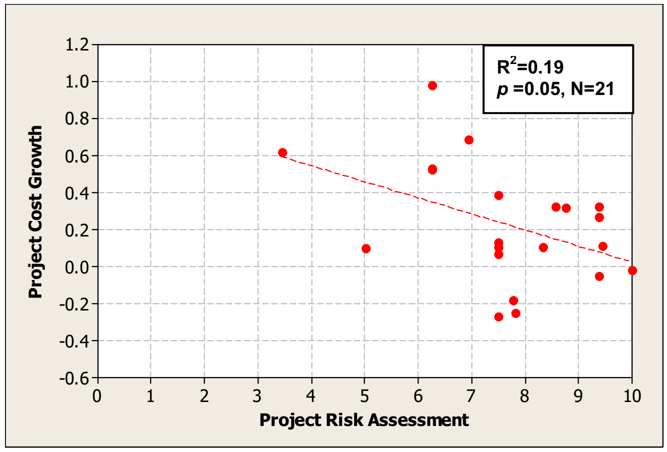


Figure 6.17 Project Cost Growth vs. Project Risk Assessment

6.2.1.3 Constructability

Constructability refers to the effective and timely integration of construction knowledge into conceptual planning, design, construction, and field operations of a project to achieve overall project objectives (CII, 2006). The author anticipated that the higher the constructability, the lower the project schedule growth. As shown in Figure 6.18, the results show that high use of constructability may lead to better project schedule performance (i.e. lower project schedule growth) with a statistically significant regression model, but low *R*-squared value (R^2=0.28, *p*=0.01, *N*=24). This means that the level of implementing constructability on projects can account for 28% of the variation in project schedule growth. However, the effect of constructability on cost performance is not significant. Results may be surprising, but are consistent with previous analysis performed by CII on the value of best practices that constructability tends to be more beneficial on schedule performance than cost. The results support the author's expectations that as constructability increases, project schedule growth decreases. The more pervasive the knowledge transfer, the more efficient the construction phase, and thus, the lower the project schedule growth.

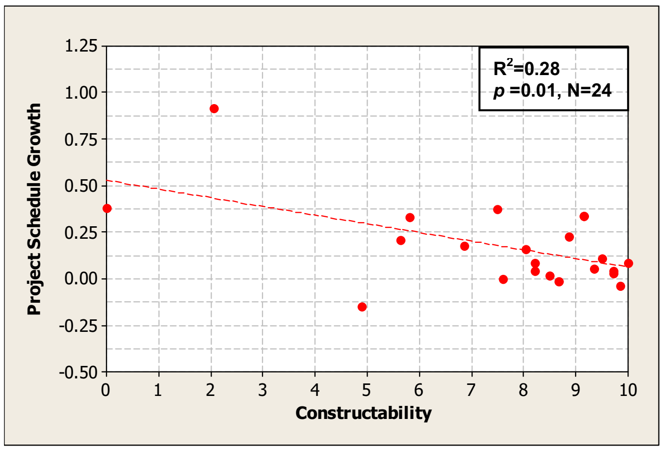


Figure 6.18 Project Schedule Growth vs. Constructability

6.2.1.4 Materials Management

Materials management is an integrated process for planning and controlling efforts to make certain that the quality and quantity of materials and equipment are specified in a timely manner and are available when needed (CII, 1999). The author anticipated that more focus on materials management would improve schedule performance, especially the construction phase. As shown in Figure 6.19, the results met expectations with a statistically significant regression model and medium *R*-squared value (R^2=0.311, p=0.01, N=23). This means that level of material management implementation can account for 52% of the variation in construction schedule growth. Improper materials management is a major contributor to delay in construction, thus it is reasonable that a high value of materials management correlates to low construction schedule growth. The results are not conclusive for the effect of material management on construction cost performance. However, the results are consistent with previous analysis performed by CII that material management tends to be more beneficial on schedule performance than cost.

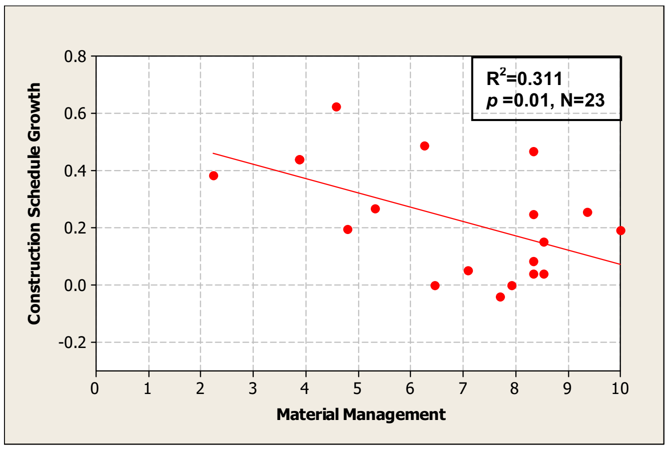


Figure 6.19 Construction Schedule Growth vs. Materials Management

6.2.2 Summary of Relationships between Project Performance and Best Practices

In this section, the additional results of relationships between project performance and best practices are presented. As mentioned in Section 6.2, Pearson's correlation was conducted to determine the relationship results. Tables 6.3 to 6.5 summarize the Pearson's correlation results for each best practice and project performance metric. Generally, the author expected that the higher the implementation of best practices, the larger the benefits to project performance. That is, a negative correlation between project performance (i.e. a lower value indicates high project performance) and best practice implementation (i.e. a high number indicates high implementation). However, some best practices may result in positive correlations with project performance, this is because one best practice may improve one project performance component while sacrificing others or vice versa. As the results show in Tables 6.3 to 6.5, some simple regressions of the factors resulted as expected by the author. Moreover, there are not many relationships indicating statistically significant correlations. This may be explained by the small sample size at this point of the study. The author believes that analyses with larger sample sizes will provide stronger correlations and also produce more statistically significant relationships.

The following sections provide high level discussions on the relationships between major performance metrics and best practices. The performance metrics that are described in detail in this section are the following: project cost growth, schedule growth, total change cost factor, rework factor, lost time severity, and CPM index.

Table 6.3 Correlations of Project Performance with Best Practices

Performance Metrics	Practices											
	FEP [1]		PDRI		PRA		Team Building		Alignment		Design for Maintainability	
	N	r	N	r	N	r	N	r	N	r	N	r
COST												
Project Cost Growth	21	0.560*	17	0.119	21	-0.436*	22	0.197	21	0.308	15	-0.314
Project Budget Factor	21	0.510*	17	-0.165	5	0.252	22	0.151	21	0.265	15	0.075
Construction Phase Cost Growth	16	0.532*	12	0.281	5	0.170	17	0.098	17	0.118	14	-0.437
Construction Indirect Cost Growth	15	0.731*	11	-0.444	15	-0.205	16	0.192	16	0.431	13	-0.078
Startup Cost Growth	10	0.544	©	©	©	©	10	-0.517	10	-0.411	9	-0.625
SCHEDULE												
Project Schedule Growth	23	0.224	19	-0.134	7	0.083	23	-0.200	22	-0.321	17	-0.230
Project Schedule Factor	23	-0.097	19	-0.229	7	0.431	23	-0.195	22	-0.368	17	-0.079
Construction Phase Schedule Growth	22	0.333	18	0.062	7	-0.166	22	-0.215	21	-0.268	16	-0.487
Startup Schedule Growth	19	0.142	15	0.152	6	0.179	18	-0.207	18	-0.411	14	-0.204
CHANGES												
Total Change Cost Factor	16	0.126	12	0.249	16	0.158	15	0.025	15	0.202	11	0.284
Development Change Cost Factor	11	0.285	©	©	11	-0.775*	11	0.002	11	0.163	9	-0.670*
Scope Change Cost Factor	13	0.432	9	-0.441	13	0.032	13	-0.077	13	0.365	8	-0.402
REWORK												
Field Rework Cost Factor	9	-0.390	©	©	9	0.415	8	0.636	8	0.282	©	©
SAFETY												
Lost time Frequency (LTF)	8	-0.815*	©	©	8	0.610	8	0.565	8	0.316	©	©
Lost Time Severity (LTS)	18	0.300	14	-0.505	18	-0.322	17	0.111	17	0.247	13	-0.203
PRODUCTIVITY												
Construction Productivity (CPM Index)	19	0.316	16	0.132	19	-0.221	19	-0.540*	18	-0.397	13	-0.768*

[1] Front End Planning

© Indicate small sample size (N<8).

r = Pearson correlation; * Indicates statistically significant correlation between factors and performance metrics at alpha level of 0.05.

Shaded cells indicate variables and relationship with their scatter plots and regression analyses provided in Chapter 6.

Table 6.4 Correlations of Project Performance with Best Practices (Continued)

Performance Metrics	Practices									
	Constructability		Material Mgmt.		Change Mgmt.		Zero Accident Tech.		Quality Mgmt.	
	N	r	N	r	N	r	N	r	N	r
COST										
Project Cost Growth	22	-0.036	22	-0.394	22	-0.050	19	0.460*	21	0.001
Project Budget Factor	22	0.066	22	-0.376	22	-0.165	19	0.282	21	0.050
Construction Phase Cost Growth	17	-0.284	17	-0.240	17	-0.033	15	0.427	17	-0.386
Construction Indirect Cost Growth	16	-0.091	16	0.116	16	0.364	14	0.559*	16	-0.288
Startup Cost Growth	10	-0.375	10	-0.351	10	-0.559	10	0.533	10	-0.094
SCHEDULE										
Project Schedule Growth	24	-0.528*	24	-0.635*	24	-0.182	21	0.107	23	-0.171
Project Schedule Factor	24	-0.296	24	-0.534*	24	-0.291	21	-0.202	23	-0.171
Construction Phase Schedule Growth	23	-0.474*	23	-0.523*	23	-0.340	21	0.288	22	-0.209
Startup Schedule Growth	19	-0.715*	19	-0.299	19	-0.060	19	0.206	19	-0.408
CHANGES										
Total Change Cost Factor	16	0.091	16	0.338	16	0.305	16	0.213	16	0.174
Development Change Cost Factor	11	-0.379	11	-0.477	11	0.075	11	0.325	11	0.161
Scope Change Cost Factor	13	-0.108	13	0.050	13	0.177	13	0.462	13	-0.227
REWORK										
Field Rework Cost Factor	9	0.351	9	0.181	9	0.088	9	-0.594	9	0.425
SAFETY										
Lost time Frequency (LTF)	8	0.461	8	-0.077	8	-0.204	8	-0.003	8	0.247
Lost Time Severity (LTS)	18	0.217	18	-0.654*	18	-0.350	18	0.045	18	0.412
PRODUCTIVITY										
Construction Productivity (CPM Index)	20	-0.312	20	0.000	20	-0.170	19	0.077	19	-0.201

© Indicate small sample size (N<8).
r = Pearson correlation; * Indicates statistically significant correlation between factors and performance metrics at alpha level of 0.05.
Shaded cells indicate variables and relationship with their scatter plots and regression analyses provided in Section 6.3.2.

Table 6.5 Correlations of Project Performance with Best Practices (Continued)

Performance Metrics	Practices							
	A/I Technology		Planning for Startup		PPMOF		Workface Planning	
	N	r	N	r	N	r	N	r
COST								
Project Cost Growth	20	-0.617*	20	0.808*	19	0.278	©	©
Project Budget Factor	20	-0.481	20	-0.731*	19	0.364	©	©
Construction Phase Cost Growth	15	-0.584*	15	-0.750*	14	0.086	©	©
Construction Indirect Cost Growth	14	-0.619*	14	-0.515	13	0.345	©	©
Startup Cost Growth	10	-0.588	10	-0.450*	9	-0.253	©	©
SCHEDULE								
Project Schedule Growth	21	-0.358	22	-0.431*	21	0.331	©	©
Project Schedule Factor	21	-0.012	22	-0.365	21	0.055	©	©
Construction Phase Schedule Growth	20	-0.508*	22	-0.429*	21	0.053	©	©*
Startup Schedule Growth	18	-0.311	19	-0.087	18	0.213	©	©
CHANGES								
Total Change Cost Factor	15	-0.399	16	0.356	15	0.266	©	©
Development Change Cost Factor*	11	-0.437	11	-0.544	10	-0.322	©	©
Scope Change Cost Factor*	13	-0.362	13	-0.270	12	0.376	©	©
REWORK								
Field Rework Cost Factor	8	0.717*	9	0.518	9	0.368	©	©
SAFETY								
Lost time Frequency (LTF)	8	0.759*	8	0.034	©	©	©	©
Lost Time Severity (LTS)	17	-0.237	18	-0.748*	17	0.407	©	©
PRODUCTIVITY								
Construction Productivity (CPM Index)	18	-0.368	19	-0.023	18	-0.166	©	©

6.2.2.1 Project Cost Growth

Among the 14 best practices shown in Tables 6.3 to 6.5, the results indicate statistical significance with negative correlation between project cost growth versus project risk assessment (r=-0.44, p=0.05, N=21), and automation/integration technology (r=-0.62, p=0.00, N=20). This means that more time spent on risk assessment, or implementation of technology onsite may lead to project cost savings. The author expects that these results will remain consistent with a larger dataset. On the other hand, the results of front end planning, zero accident techniques, and planning for startup are not aligned with the previous studies conducted by CII. These conflicting results may be due to the small sample size used in this study or the assessment of these three practices. As a result, further research is required to examine these relationships.

6.2.2.2 Project Schedule Growth

Tables 6.3 to 6.5 indicate medium to high statistically negative correlations between project schedule growth and the following practices: 1) material management (r=-0.64, p=0.00, N=24), 2) constructability (r=-0.53, p=0.01, N=24), and 3) planning for startup (r=-0.43, p=0.05, N=24). This is also in line with CII's previous studies that efficient management of materials and sufficient availability of installed equipment on site could save time and improves schedule performance. This conclusion is similar to the benefits attained when more construction reviews for design usability are conducted and effective planning for the startup phase is performed. Correlations, however, between prefabrication and modularization (PPMOF) and schedule growth (r=0.33, p=0.14, N=21) were not expected. This is inconsistent with Alberta expert opinions because modularization is commonly used and believed to be strategic for fast-track schedules. These conflicting results may change as the sample gets larger, but it may also indicate problems with preassembly operation these projects. Analysis with a larger sample size may produce the industry anticipated results. Also, even with a larger dataset, the CII modularization strategies may require adaptation for Alberta projects to better confront its environmental challenges.

6.2.2.3 Project Development Change Cost Factor

Tables 6.3 to 6.5 indicate high statistically negative correlations between project development cost factor and project risk assessment (r=-0.78, p=0.01, N=11) and design for maintainability (r=-0.67, p=0.05, N=9). The results indicate a statistically significant strong correlation between development change cost factor and project risk assessment (PRA), which is similar to that of design for maintainability. The results are aligned with industry perception that the better the risk assessment early on, the lower the number of changes on the projects. This is consistent with the observation that in Alberta, project teams commonly mitigate the high cost of changes by including high contingency budgets. Though the results from this study were in line with industry perception, conclusions should be drawn with caution due to the small sample size used in this analysis.

6.2.2.4 Rework Factor

The results shown in Tables 6.3 to 6.5 indicate statistically significant positive correlations between rework factor and automation/integration technology (r=0.717, p=0.05, N=8). Although data are provided by only 8 projects, the results indicate that the more automation and technology used on projects, the higher the anticipated rework cost. This result seems counter-intuitive because the technology use is perceived to be advantageous to improving work quality. Many believe high technology implementation, for example with engineering work, will lead to higher accuracy and greater engineering detail that will facilitate work on site. However, the value of AI Tech may not show up in the early stages of implementation. Technology integration demands time in that workers must confront a learning curve. Therefore, it is suggested by the author that a larger dataset is obtained to draw conclusions on the relationship between AI Tech and rework.

6.2.2.5 Safety Performance

Although there was a small number of projects that reported safety data in the Alberta database, the data analysis on the safety performance as measured by lost time frequency (LTF) yield intuitive results. The results indicate a statistically significant negative correlation with front end planning (r=-0.82, p=0.01, N=8) and AI Tech (r=-0.82, p=0.01, N=8). This is in line with the industry perception that the solid project planning supports a safer workplace and leads to fewer accidents. Similarly, the use of technology for work integration, detailed drawings and high tech equipment may favorably impact the number of accidents.

6.2.2.6 Construction Productivity Project Level (CPM Index)

The author expected to see distinct relationships between CPM index and material management, prefabrication (PPMOF), constructability, AI Tech and workface planning. These five practices are believed to provide information to project teams and facilitate thorough planning for material and equipment availability, which could lead to improved onsite labor productivity. However, with a limited number of data, Tables 6.3 to 6.5 indicate low correlation between each of these practices and the CPM index. At this point in this study, the results shown in Tables 6.3 to 6.5 indicate statistically significant correlations between CPM index and only design for maintainability (r=-0.77, p=0.00, N=13) and team building (r=-0.54, p=0.02, N=19). In addition, the results indicate AI Tech and alignment for pre-project planning are approaching statistical significance. The author expects that a larger dataset will reveal benefits between the five practices and construction productivity.

6.3 CHAPTER SUMMARY

In this chapter, the inferential statistics revealed several significant relationships between project characteristics, and execution strategies on project cost, and schedule performance. The results indicate a large reduction in construction cost growth with increased engineering prior to the start of construction. Since Alberta projects are typically schedule-driven, some Alberta projects start construction with less than 30% engineering completed. The preliminary analyses indicate, however, that engineering percent complete of 65% to 70% before construction start may be of benefit for reducing construction cost for fast tracked projects. In addition, it also found that an inaccurate peak construction work force estimate is related to high cost growth, due to higher expenses of unexpected indirect costs. Also, larger projects tend to have higher construction indirect cost growth than anticipated in their estimates.

The results also suggest some value from best practices implementation. Better project risk assessment implementation and higher use of automation/integration technology may improve project cost performance.

Additionally, the more prominent the use of constructability and materials management, the greater the benefit with respect to project schedule. It is essential to note that the results are based upon analysis of simple bivariate relationships. Other direct and indirect impact of factors should also be considered in the data analysis when more project data are available.

In conclusion, the overall analysis results presented in this chapter strongly supports the first hypothesis statement and the ability to use these metrics for inferential analyses. Various relationships between metrics and factors were explored and many of these were statistically significant despite the small sample sizes. The results were also presented and confirmed by more than 50 industry experts in Alberta who are representatives from both owner and contractor companies. The results were in agreement with industry expert opinion, and to some degree in line with the experts' company practices. Critical factors impacting Alberta projects' cost and schedule performance were discovered; however, further analyses with larger datasets should reveal many more relationships. Finally, factors affects cost and schedule performance for Alberta projects were identified per hypothesis two.

CHAPTER 7:
IMPACT FACTORS AFFECTING PROJECT PERFORMANCE

This chapter consists of two main analyses: the first was to identify the significant factors impacting project performance, and the second analysis focused on quantifying relative impact of the identified factors. The first analysis establishes Hypothesis 2 of this study, using the methodology shown in Figure 7.1. The purpose is to identify the factors which significantly impact Alberta project performance and rank them by the importance of each factor on project performance. To accomplish this, the Project Impact Factor data from the Alberta benchmarking questionnaire in Section 6.3 were analyzed. The final step of the first analysis was to explore the influence of the aggregated impact of the factors on project cost, schedule, and construction productivity on a project by project basis. Details of the first analysis are described in Section 7.1 to 7.2.

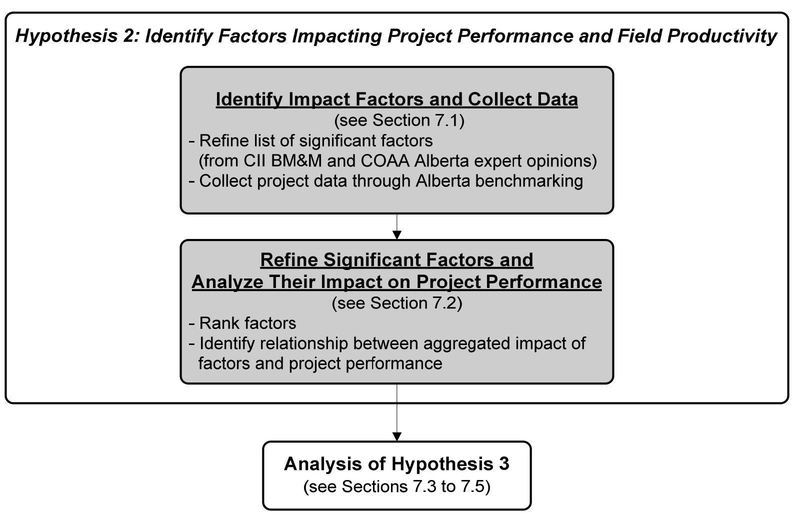


Figure 7.1 Analysis of the Second Hypothesis

The second analysis was conducted to support the third hypothesis of this study which focuses on quantifying the relative impacts of factors on construction productivity, as shaded boxes shown in Figure 7.2. The two data sources utilized were the Alberta benchmarking database and the additional survey of project practitioners. The first part of the analysis used the Alberta benchmarking data to identify significant impact factors. Then these factors were validated by the data from the additional survey of project practitioners. Finally, this second analysis yielded factors and their impacts associated with the *CPM Index*, as described in Sections 7.3 to 7.5 of this chapter.

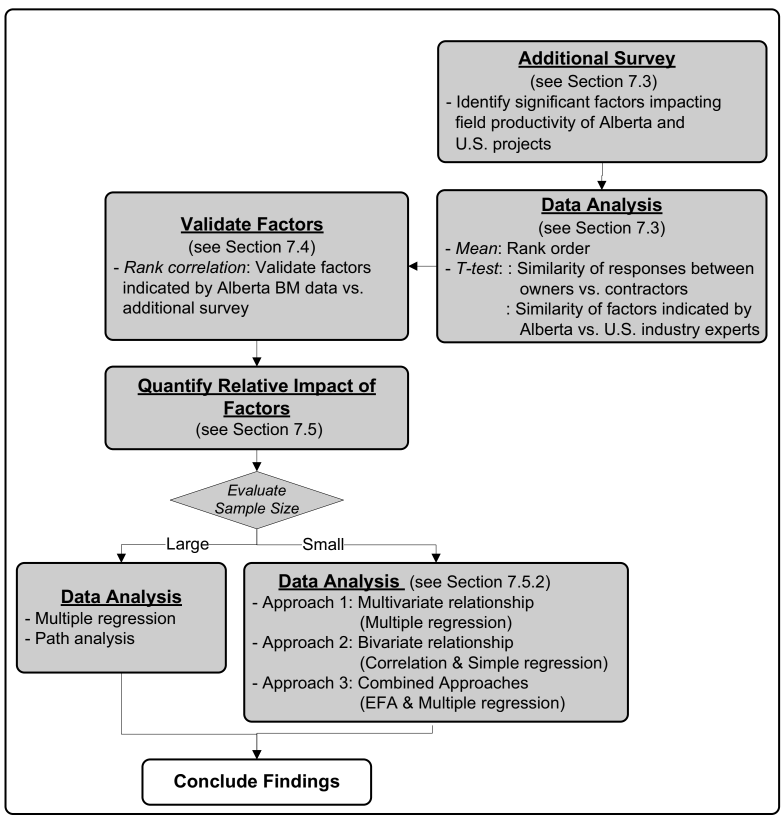


Figure 7.2 Analysis of the Third Hypothesis

7.1 Rank of Factors Impacting Project Performance

In this study, the impact of 18 potential factors on project cost, schedule, and construction productivity were assessed. The entire list of these 18 factors is shown in Table 7.1. Beyond the 12 impact factors routinely assessed by CII BM&M, the COAA Benchmarking Committee requested the addition of six factors specific to Alberta-based projects, as shown in the right hand column of Table 7.1. A detailed description of each factor can be found in Appendix A.

Table 7.1 List of Impact Factors Measured in Alberta Benchmarking

CII BM&M Factors	Additional factors
1. Weather conditions	13. Quality of field level supervision
2. Labor availability	14. Amount of scheduled overtime
3. Material availability	15. Amount of unplanned overtime
4. Site conditions	16. Engineering labor skills
5. Project complexity	17. Percent engineering completed prior to project sanction
6. Detail engineering design location (use of offshore engineering)	18. Percent engineering completed prior to construction start
7. Project team experience	
8. Craft labor skill	
9. Project team turnover	
10. Regulatory requirements	
11. Business market conditions	
12. Coordination with plant shutdown	

Project teams were asked to assess how each of these factors adversely or positively affected project performance beyond anticipated conditions. Participants expressed their opinions regarding the impact of each factor on project performance subjectively from a "highly negative" effect to a "highly positive" one or somewhere in between. The degree of impact of each factor was numerically rated in a range from -2 to +2, where -2 represented a highly negative impact, and +2 represented a highly positive impact. A neutral rating of zero indicated the impact of the factor was adequately prepared for or "as planned." An excerpt from the Alberta benchmarking questionnaire is shown in Figure 7.3.

6.3 Project Impacts

The following section is intended to assess whether environmental or market conditions adversely or positively affected project performance ***beyond the conditions for which you planned.***

Impacts may be assessed ranging from "highly negative", to "highly positive". If the factor was adequately planned for, please indicate "As Planned". If it was not adequately planned for, please indicate the impact, positive or negative. Negative impacts adversely affect the metrics and positive impacts favorably affect the metrics.

The impact of the percentage of engineering completed prior to construction start

◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Figure 7.3 Excerpt of Questions to Assess Degree of Impact of Factors from Alberta Benchmarking Questionnaire

The subjective assessment from the project teams as mentioned above were analyzed to determine the relative impact among factors on project cost, schedule and construction productivity. The factors were ranked based upon each factor's average degree of impact as perceived by the project teams. In addition, the variability of impact of each factor on each project performance metric is also presented to determine the potential for improvements. The survey results for the factors impacting project cost, schedule and construction productivity are as shown in Figures 7.4 to 7.6. The *N* represents the number of projects which reported a degree of impact due to a particular factor. The impact factors associated with each project performance metric with less than ten responses were not included in this analysis, as was the case with engineering productivity.

As seen in Figures 7.4 to 7.6, the factors were ranked by average degree of impact as indicated by the symbol♦, from highest negative impact on project performance to highest positive impact, from top to bottom. Negative impact indicates project teams perceived a negative effect due to the factor beyond the conditions for which they planned. This may be due to inefficiency of risk assessment, inexperience of the project team, or an unexpected situation, such as severe environmental conditions. Accordingly, positive impact indicates project teams perceived a favorable effect attributable to a factor. It can be inferred from a positive response that the project team had a well-conceived plan and developed execution strategies to neutralize adverse impacts stemming from these factors.

The whisker line was used to present impact variability for each factor as perceived by the project team. The whisker line spanned one standard deviation (S.D.) in both directions from the average (mean) impact. A longer whisker line for a factor indicates greater variation for a factor impacting project performance was perceived by project teams. This implies that the project team may have had the potential to improve the project's performance by mitigating the negative impact of the factor. On the other hand, a shorter whisker line indicates that the survey participants experienced similar impacts, and it implies that there is less potential for projects to experience vast improvement or decline.

7.1.1 Factor Ranking by Degree Impact on Project Cost Growth

As shown in Figure 7.4, on average, the project teams in the Alberta dataset indicated moderate to severe burdens from the impacts of the 16 factors on project cost beyond the conditions for which the teams planned. The factor which is perceived to have the greatest adverse impact on project cost is the *amount of unplanned overtime* with an average impact of -0.889. Other top factors are *percent engineering completed prior to construction start* and *business market conditions* (tied average impact of -0.722), *craft labor skill* (-0.565), and *plant shut down coordination* (-0.500).

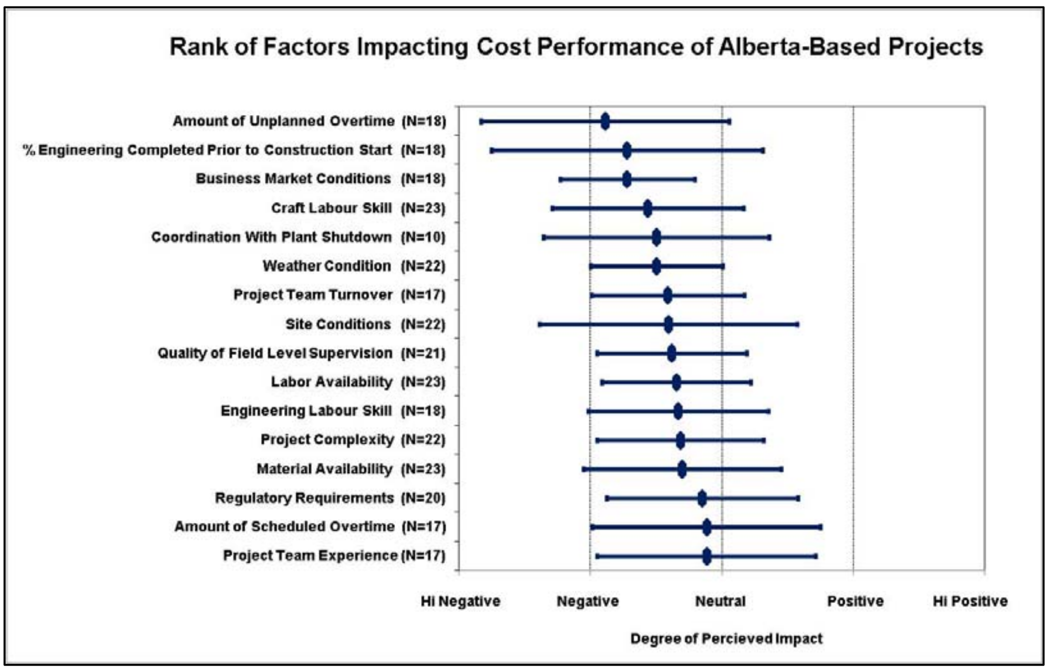


Figure 7.4 Factors Ranked by Mean Degree of Impact on Project Cost Growth

The results indicate that all projects in the dataset experienced negative impacts due to a high *amount of unplanned overtime*. This conclusion is illustrated by the whisker line, which falls exclusively within the negative region of the diagram, thus indicating the project teams' inability to counter the adverse impacts of unplanned overtime. The survey results point out that the project teams perceived a lack of foresight with respect to overtime growth, and they recognized that the negative impact of *unplanned overtime* highly influence project cost growth. This is in line with industry opinions that unplanned overtime is one of the most critical issues that drives cost overrun on Alberta projects. Based on the survey results, the author recommends that project teams focus their efforts on minimizing the impact of factors from the highest ranked factor down.

Percent engineering completed prior to construction start and other ranked factors, such as *business market conditions, craft labor skill*, and *coordination with plant shutdown,* are factors that the project teams can manage in advance and control to some degree to minimize the degree of impacts. *Percent engineering completed prior to construction start* was reported to be the second highest factor influencing project cost. Also, it produced the greatest variation of impact on project cost (i.e. longest whisker line). This implies that *percent engineering completed prior to construction start* is a more responsive factor and allow greater room for project cost saving. A high degree of engineering completion should allow better definition and favorable effect on project cost. This conclusion is in line with the results drawn in the previous chapter of this research that percent engineering completeness is one of the most important factors leading to significant project cost overrun on Alberta projects. Lastly, *regulatory requirements* were found to be the factor with the least variance in S.D. (i.e. shortest whisker line). The result implies that high *regulatory requirements* afford fewer opportunities to influence because it affects project cost consistently with little variance.

In sum, the results suggest that in order to minimize project cost overruns, project teams should increase *percent engineering completed prior to construction start*. The project teams should reduce the need for unplanned overtime and also adjust their execution strategies with respect to controllable factors, which have a high negative impact (i.e. highly ranked) and high sensitivity (i.e. long whisker line). These factors include, but are not limited to, *business market conditions*, *craft labor skill*, and *plant shut down coordination*. Effective mitigation of the impacts of these factors will allow for high potential for project cost performance improvement.

7.1.2 Factors Ranked by Degree of Impact on Project Schedule Growth

As shown in Figure 7.5, on average, the project teams perceived the burden of adverse schedule impacts from the 18 factors beyond what they had planned for. The exception was *coordination with plant shutdown*, which had a positive average impact on project schedule. This indicates the perception that Alberta projects were not likely to be affected by plant shutdown during construction. The results shown in Figure 7.5 indicate that *percent of engineering completed prior to construction start* is perceived to have the greatest adverse impact and variation on project schedule growth. In addition, the other the top factors negatively impacting project schedule as follows: *business market conditions* (-0.611), *craft labor skill* (-0.565), and *quality of field level supervision* and *weather conditions* (tied at -0.524).

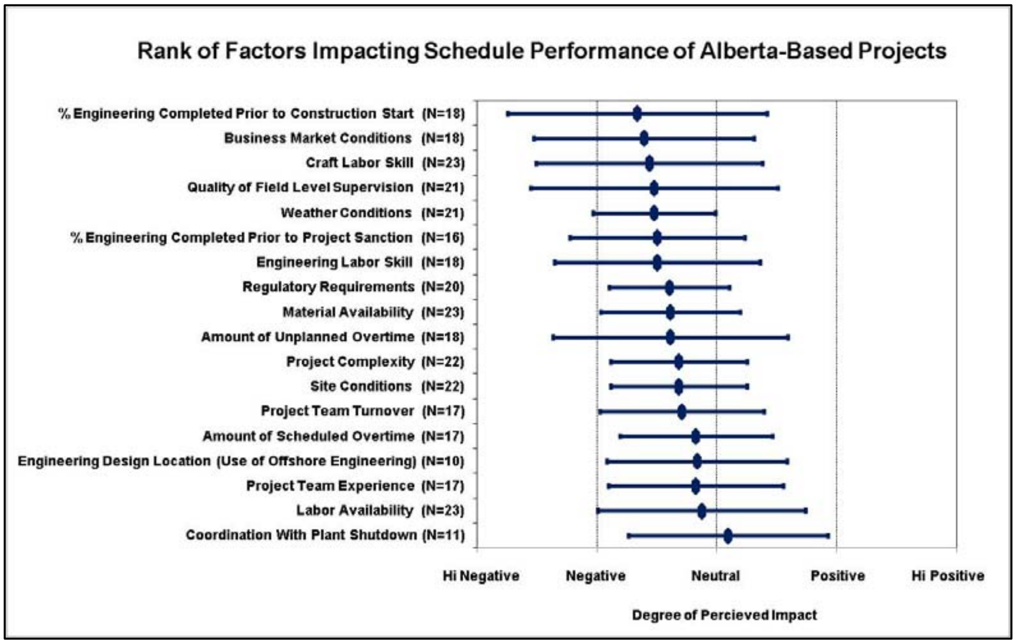


Figure 7.5 Factors Ranked by Mean Degree of Impact on Schedule Performance

For project schedule performance, it can be seen that all of the top five factors are controllable factors for which the project teams can develop execution strategies to mitigate the impacts. It is interesting that the top factors impacting project schedule are very similar to those for project cost growth, as shown in Figure 7.4. This is due to the fact that schedule delays are contributable to project cost overrun. In terms of the variations in impacts of the factors, the project schedule results are consistent with those of project cost. *Percent engineering completed before construction start* is the factor with the greatest S.D. (i.e. longest whisker line), while *regulatory requirements* is the factor with the least S.D. (i.e. shortest whisker line). The results indicate the industry perception that *percent engineering complete before construction start* is more volatile and its impact can vary significantly based on the level of implementation of the factor. On the other hand, *regulatory requirements* are perceived to be less flexible for improvement in project schedule performance. It is also worth mentioning that *weather conditions* were perceived by project teams to have greater impact on project schedule than project cost. All projects in the dataset experienced negative schedule impacts due to severe *weather conditions* (i.e. the whisker line falls only within the negative impact region). This indicates that the project teams were either not adequately prepared for the severe *weather conditions* or their mitigation measures were not effective enough to counter the severe weather endured.

In sum, the results suggest that in order to minimize project schedule overruns, project teams should increase the level of engineering completeness before construction execution. Also, the results suggest that project teams should adjust their execution strategies, focusing on factors with high negative impact and high sensitivity (i.e. long whisker line). It should be noted that all factors ranked at the top are controllable factors, such as *engineering completeness before construction start, business market conditions*, *craft labor skill*, *quality of field supervision*, and *weather conditions*. Effective mitigation of the impacts of these factors will allow for higher potential project schedule performance improvement.

7.1.3 Factors Ranked by Degree of Impact on Construction Productivity (CPM Index)

As shown in Figure 7.6, on average the projects from the database experienced the burden of negative impact on construction productivity from 17 factors. The top five factors impacting construction productivity perceived by the Alberta project teams are: *percent of engineering completed prior to construction* *start* (-0.833), *amount of unplanned overtime* (-0.778), *business market conditions* (-0.765), *quality of field level supervision* (-0.476), and *craft labor skill* (-0.455).

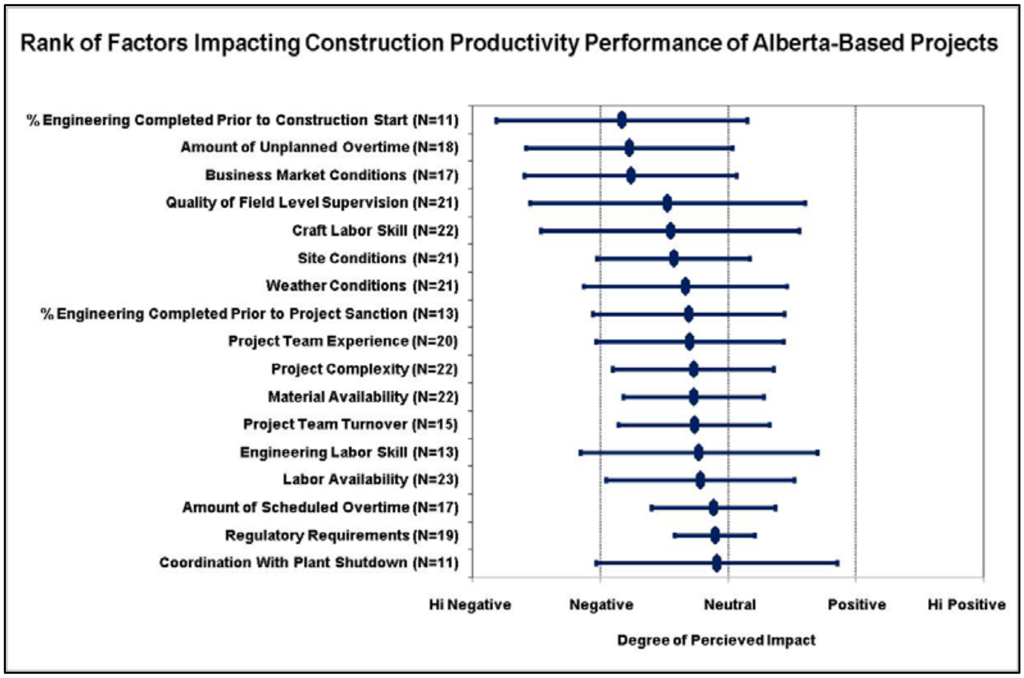


Figure 7.6 Factors Ranked by Degree Impact on Construction Productivity

Interestingly, the top five factors impacting construction productivity at the project level (CPM index) are a combination of the top five factors impacting project cost and schedule. This may be because construction productivity is a major contributor to project schedule and cost. Similarly to the results for project schedule, the *percent engineering completed prior to construction start* is perceived by the Alberta project teams to have the greatest impact on construction productivity. As indicated by the whisker line falling mostly within the negative region of the plot, most project teams discerned adverse impact due to insufficient engineering completed prior to construction start. In terms of impact variation, *quality of field* *level supervision* has the largest variation, which indicates more opportunity for management improvement than other factors on construction productivity but less average impact. This means that high *quality field level supervision* can lead to a favorable effect on onsite productivity; however its impact is not extreme. If a project falls near the high negative area on the whisker line (values between -1 S.D. and the mean), the project team has more opportunity to improve the project's construction productivity by focusing attention on onsite supervision, for example.

In sum, the results suggest that in order to improve the construction productivity of their projects, the project teams should increase the level of *engineering completed prior to construction start* and also the *quality of field level supervision*. These two factors are indicated to have the highest adverse impacts and largest variations with respect to construction productivity. Also, the results suggest that the project teams should adjust its execution strategies to target controllable factors, which have a high negative impact and high sensitivity (i.e. long whisker line), such as *business market condition* and *craft labor skill*. Effective mitigation of the impacts of these factors will allow for greater potential construction productivity at the project level.

7.1.4 Section Summary

The overall results from Section 7.1.1 to 7.1.3 indicate the perception of Alberta project teams that the *percent engineering completed prior to construction start* is the most influential and common factor adversely impacting project cost, schedule and construction productivity. This result is consistent with industry perception and the data analysis results described in Section 6.1. The results suggest that project teams should have a sufficient level of engineering completed before construction execution to improve construction productivity, project schedule, and finally cost performance. This can be explained because the higher the amount of engineering completed prior to construction start, the better the construction phase planning and the higher the productivity onsite. This then leads to more control on project schedule and cost. In addition, other manageable factors, as shown in the construction productivity results, are critical factors for improvement since construction productivity is linked to schedule delay and project cost growth. These critical manageable factors are *business market conditions*, *quality of field level supervision*, and *craft labor skill*. To a certain degree, the project teams can develop strategies to encounter or mitigate the degrees of impact from these factors.

7.2 EFFECT OF AGGREGATED IMPACT OF FACTORS ON PROJECT PERFORMANCE

The purpose of this section is to quantify the effect of impact factors on overall project performance (i.e. cost, schedule, and construction productivity). It was not feasible to analyze the relative impacts of each factor individually due to limitations in data availability. Specifically, every factor does not have cost, schedule, and construction productivity data in the Alberta benchmarking database. Thus, this study utilizes an aggregated impact of factors to determine the combined effect of all factors on Alberta project performance.

The analysis in this section is on a project by project basis. The perceptions from the project teams on 16 impact factors shown in Figure 7.4 are aggregated for project cost analysis, the 18 factors in Figure 7.5 are aggregated for project schedule analysis, and the 17 factors in Figure 7.6 are aggregated for construction productivity analysis. The aggregated impact of the factors for each project was calculated by summing up the subjective assessments of the degrees of impact of each factor. Then, the sum of the degrees of impact for each factor (1) was adjusted by eliminating the missing data to produce the adjusted sum score (3). Finally, the adjusted sum score was standardized based upon the original scale onto a scale from -10 to +10 to generate the aggregated impact score (5). If a project scores a –10, it endured the highest cumulative negative impact due to the group of factors beyond what was planned for, and a +10 score would indicate the project endured the highest cumulative positive impact of factors. A sample calculation is shown in Table 7.2.

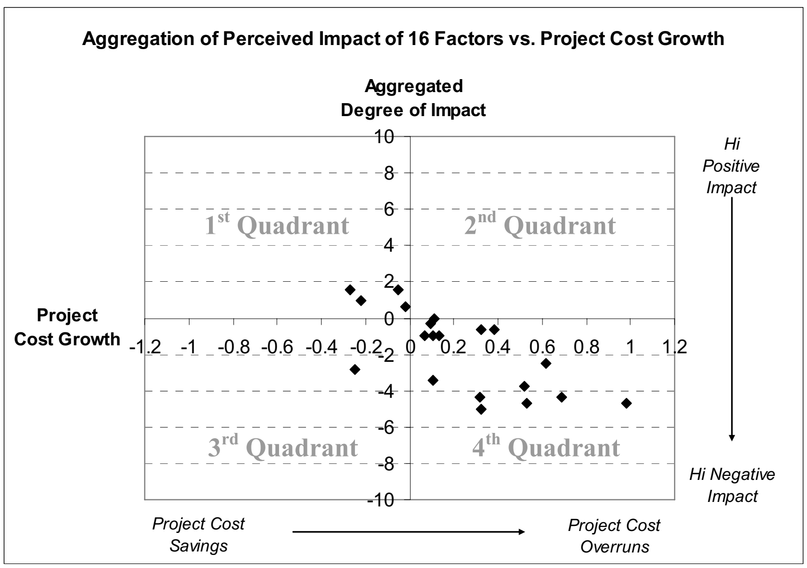
Table 7.2 Sample Calculation of the Aggregated Impact of Factors on a Project

- As mentioned in Section 7.1, the assessment of the degree of impact is in a range of -2 to +2, where -2 indicates a highly negative impact.

Impact Factors	Impact on Cost (16 factors)	Impact on Schedule (18 factors)	Impact on Construction Productivity (17 factors)
1. Weather conditions	-1	0	1
2. Labor availability	-1	1	1
3. Material availability	-1	-1	0
4. Site conditions	-1	-1	-1
5. Project complexity	-1	-1	0
6. Detail engineering design location (use of offshore engineering)		0	
7. Project team experience	-1	-1	0
8. Craft labor skill	-1	-1	1
9. Project team turnover	-1	No data	0
10. Regulatory requirements	-1	0	0
11. Business market conditions	-2	-1	No data
12. Coordination with plant shutdown	-1	No data	No data
13. Quality of field level supervision	-1	-1	1
14. Amount of scheduled overtime	0	0	0
15. Amount of unplanned overtime	-1	No data	0
16. Engineering labor skills	-1	-1	0
17. Percent engineering completed prior to project sanction		-1	0
18. Percent engineering finished before construction start	-1	-1	0
Sum score (1)	-16	-9	+3
Number of available data (2)	16	15	15
Adjusted sum score (3)	-16	-10.8	+3.40
Total Score (4) = number of factors x 2	32	36	34
Aggregated impacts (5) (total score = 10)	**-5**	**-3**	**+1**
Calculations:	(3)= (1)x16/ (2) (5)= (3)x10/(4)	(3)= (1)x18/ (2) (5)= (3)x10/(4)	(3)= (1)x17/ (2) (5)= (3)x10/(4)

7.2.1 Effect of Aggregation of Perceived Impact of Factors on Project Cost Growth

Figure 7.7 shows the relationship between the aggregated perceived impacts of the 16 factors and project cost growth metrics using 20 projects in the Alberta dataset. The figure provides evidence that a higher degree of aggregated perceived impact of the 16 factors leads to higher project cost growth. The results show that the aggregated perceived impact of factors correlate with project cost growth, which confirms the inferential ability of the measurement of the impacts of factors.



Note: ♦ represents aggregated factors for one project

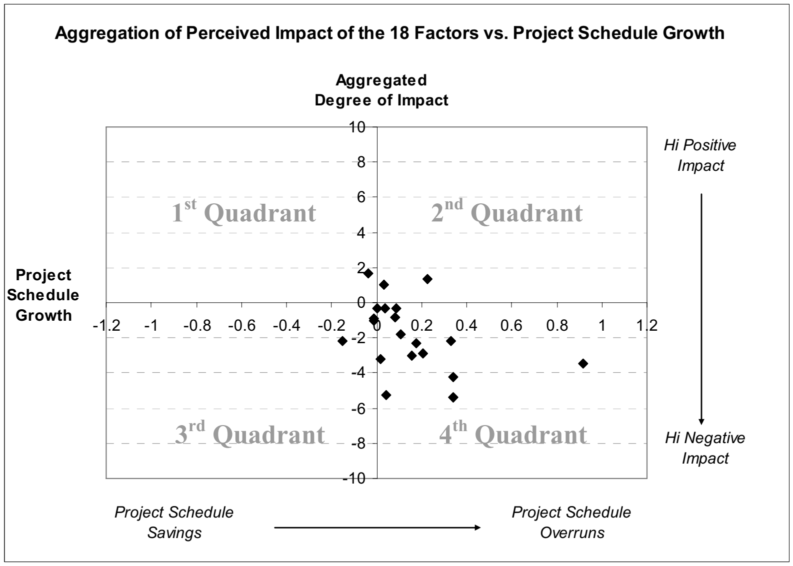
Figure 7.7 Aggregation of Perceived Impact of Factors vs. Project Cost Growth

The results shown in Figure 7.7 indicate that most Alberta projects in the dataset have cost overruns and are perceived to be affected by higher negative impacts than the conditions for which the project teams had planned. This is illustrated by most of the data points falling in the fourth quadrant of the plot, which indicates that projects with high negative aggregated perceived impact tend to have higher cost overruns. However, there are some projects falling within the first quadrant with a lower perceived adverse impact than what was planned. Generally, the greater the positive impact of the 16 factors as perceived by the project teams from what they had planned, the better the project cost performance.

7.2.2 Effect of Aggregation of Perceived Impact of Factors on Project Schedule Growth

Figure 7.8 shows the relationship between the aggregated perception from the Alberta project teams on the degrees of impact of the 18 factors and project schedule performance from 21 projects in the dataset. The figure provides evidence that a higher negative degree of aggregated perceived impact from factors leads to higher project schedule growth. The results show that the aggregated perceived impact of factors correlate with project schedule growth, which confirms the inferential ability of the measurement of the impacts of factors.

It can be seen from Figure 7.8 that most Alberta projects in the dataset have schedule overruns and are perceived to be affected by higher aggregated negative impacts than the conditions for which the project teams had planned. This is illustrated by most of the data points falling in the fourth quadrant, which indicates the higher the negative aggregated impact perceived, the higher the delay of the project schedule. However, there are few projects which experienced less perceived negative impact from the factors than anticipated. These projects are indicated by the data points falling in the first and second quadrants.

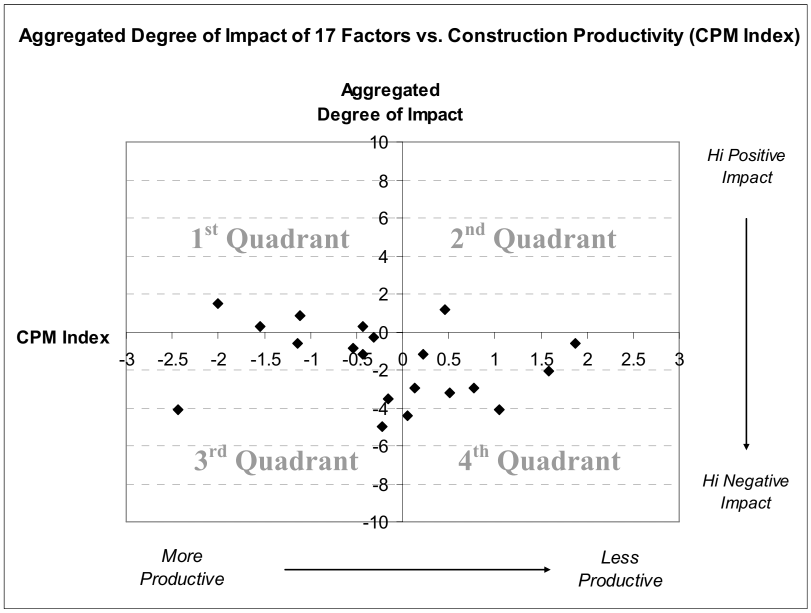


Note: ♦ represents aggregated factors for one project.

Figure 7.8 Aggregation of Perceived Impact of Factors vs. Project Schedule Growth

7.2.3 Effect of Aggregation of Perceived Impact of Factors on Construction Productivity at Project Level (CPM Index)

Figure 7.9 illustrates the relationship between the aggregated perception from the Alberta project teams on the degrees of impact of the 17 factors and construction productivity at the project level from 20 unique projects. The construction productivity at project level representing by CPM index is a relative construction productivity of a project compared to other projects, and the value ranges from -3 to +3, with -3 indicating the highest productivity. The results indicate that a high degree of negative aggregated perceived impact of factors lead to less productive field labor. The results verify that the aggregated perceived impact of factors correlate with construction productivity, which confirms the inferential ability of the measurement of the impacts of factors in this study.



Note: ♦ represents aggregated factors for one project.

Figure 7.9 Aggregation of Perceived Impact of Factors vs. Construction Productivity

Similar to the results previously presented for project cost and schedule, the project data plot shown in Figure 7.9 indicates that most Alberta projects in the dataset are perceived to be affected by higher negative impacts than the conditions for which the project teams had planned. As opposed to the plots for cost and schedule growth (Figures 7.7 and 7.8), which depict absolute data, the construction productivity plot is comprised of relative data. The productivity plot appears scattered from positive results to negative ones because the CPM index of each project in the database ranges from -3 to +3, which compares projects relatively to one another. However, it can be seen that most project teams perceived higher adverse impact of factors on productivity than that for which they planned as illustrated by the majority of the data points with aggregated impact value less than zero. Many of these projects endured a high negative aggregated impact of the factors, although some of these projects indicated high productivity (relative to other projects), as illustrated by the data points in the third quadrant (i.e. a degree of impact less than zero and CPM value less than zero). However, it can be seen that these projects with high negative perceived impact on productivity do not achieve desirable cost and schedule performance as evidenced in Figures 7.7 and 7.8. Most data from quadrants 3 on the productivity plot fall in quadrant 4 on the cost and schedule graphs, where quadrant 4 corresponds to a high negative impact and high cost/schedule overruns.

In conclusion, project teams should make an effort to minimize the aggregated impact of the 17 factors on construction productivity to enhance field productivity. Subsequently, since cost growth and schedule growth are linked to field productivity, both should be reduced by the domino effect.

7.3 IMPACT FACTORS INDICATED BY EXPERT OPINIONS FROM ADDITIONAL SURVEY

As mentioned in Section 3.2, the additional survey for project practitioners was conducted from March to September 2008 to document the opinions of construction professionals in both the U.S. and Alberta with large EMR project experience. This section is related to the steps supporting Hypothesis 3 that are shaded as shown in the figure below:

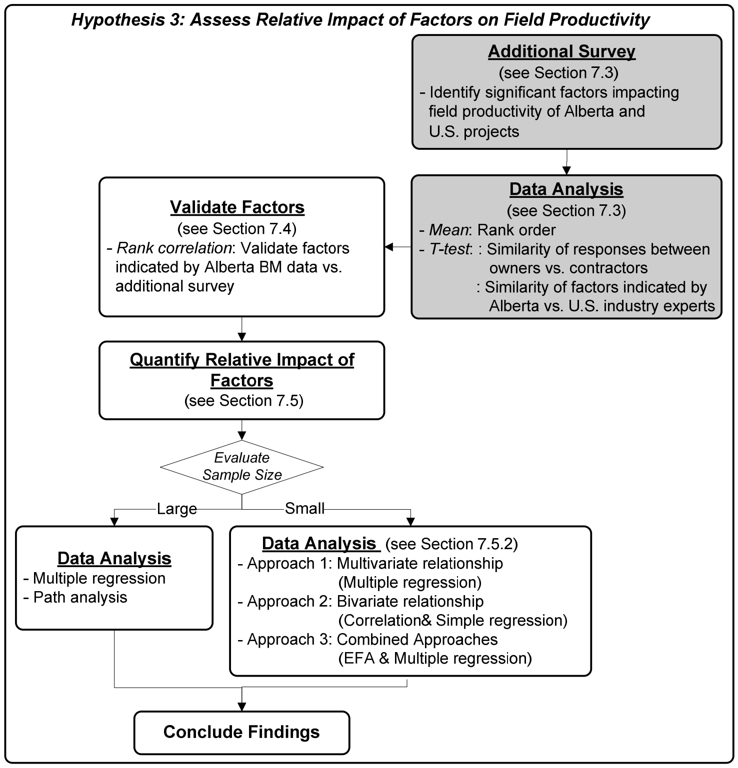


Figure 7.10 Analysis of the Third Hypothesis

Again, both Alberta and U.S. professionals were asked to rate the degree of impact of 33 factors on a scale of 0 to 10 based upon their experiences as shown in Figure 7.11. The entire list of these 33 factors can be seen in the additional survey available in Appendix F.

1. In your experience, please **Rate the Degree** to which each factor listed below **influences or impacts the Field Productivity** of construction projects.

*Scale is 1 to 10. "**1**" refers to **NO** influence or impact. "**10**" refers to **SUBSTANTIAL** impact.*

Example:

Factor	Degree affect to Field Productivity									
	No Impact				Medium Impact					Substantial Impact
1.1 A	1	2	3	4	5	6	7	8	9	10

Project Characteristics Factors	To what degree do these factors influence Field Productivity?									
	No Influence				Medium Influence					Substantial Influence
1.1 Project Size ($)	1	2	3	4	5	6	7	8	9	10
1.2 Project Nature (grassroots, addition etc)	1	2	3	4	5	6	7	8	9	10
1.3 Project Driver (cost, schedule, etc)	1	2	3	4	5	6	7	8	9	10

Figure 7.11 Excerpt of Questions from the Additional Survey for Project Practitioners

This additional data consisted of a survey population of 125 owner and contractor construction experts from the U.S. and Alberta. However, only 73 responses are included because the purpose of this study is to examine only large EMR projects with project cost in excess of $5M. A sample of the survey, detailed data collection description, and analysis results are provided in Appendix F. Table 7.3 indicates that a total of 67 respondents completed the survey consisting of 46 responses from Alberta and 27 from the U.S. The average work experience of both groups was an average of 25 years. Table 7.4 shows the number of respondents by their role in their organizations. It can be seen that the respondents' roles varied from a managerial capacity to construction operations. The majority of respondents from both groups, however, were project managers.

Table 7.3 Number of Respondents by Industry Groups

Groups	Alberta	U.S.	Total
Owner	32	8	***40***
Contractor	14	19	***33***
Total	***46***	***27***	***73***

Table 7.4 Number of Respondents by Project Role

Project Role	Alberta	U.S.	Total
Executive	3 *(7%)*	10 *(37%)*	***13***
Manager/ Director	24 *(52%)*	11 *(41%)*	***35***
Engineering Related	1 *(2%)*	-	***1***
Construction/Operation Related	4 *(9%)*	2 *(7%)*	***6***
Estimator	6 *(13%)*	1 *(4%)*	***7***
Project Controls	8 *(17%)*	3 *(11%)*	***11***
Total	***46***	***27***	***73***

Note: Number of responses (percent of response within category)

7.3.1 Difference in Perceived Impact of Factors on Field Productivity between Alberta and U.S. Industry Experts

First, the datasets were analyzed by using *t*-statistics to determine whether the perceptions of impact on each of 33 factors on construction productivity were significantly different between experts in the U.S. and Alberta. According to the preliminary *t*-test results provided in Appendix F.5, overall, the average degree of impact of each factor on construction productivity as indicated by U.S. and Alberta experts are not statistically significant different, except on these two following factors: *the number of changes* (t=2.05, p=0.04) and *labor skill* (t=2.44, p=0.02).

7.3.1.1 Rank Order of Factors Impacting Construction Productivity between Alberta and U.S.

The 33 factors impacting construction productivity were ranked by using a relative impact index. This index is a ratio of the total impact of a specific factor indicated by all respondents to the highest possible impact score. The index was calculated using the following formula:

$$Relative\,Importance\,Index = \frac{\sum r}{M \times N}$$

where r is the rating given to each factor by the respondent (a scale of 1 to 10 with 1 indicating no impact and 10 indicating substantial impact), M is the highest degree of impact (in this study, equal to 10), and N represents the total number of responses associated with the factors. A higher relative impact score indicates a relatively higher degree of impact of a factor when compared to other factors within each geographic region. Using this calculated index, the 33 productivity factors were ranked from highest to lowest impact factors as shown in Table 7.5.

Table 7.5 Major Factors Impacting Field Productivity Ranked by Industry Groups from the Survey of Project Practitioners

Variables	Relative Importance Index by Group		Rank	
	U.S.	Alberta	U.S.	Alberta
1. Supervisor competence	0.896	0.900	3	1
2. Material availability	0.854	0.880	8	2
3. Crew turnover	0.862	0.859	6	3
4. Site congestion	0.858	0.856	7	4
5. Labor skill	0.915	0.856	2	5
6. Number of changes	0.919	0.854	1	6
7. Work attitude	0.873	0.851	5	7
8. Quality of engineering	0.827	0.844	10	8
9. Labor availability	0.881	0.841	4	9
10. Management competence	0.835	0.837	9	10
11. Project team experience	0.788	0.827	16	11
12. Availability of information	0.808	0.822	12	12
13. Workface planning	0.804	0.805	14	13
14. Front end planning	0.758	0.795	18	14
15. Weather conditions	0.792	0.793	15	15
16. Project complexity	0.827	0.778	11	16
17. Constructability	0.808	0.776	13	17
18. Percent Prefabrication	0.758	0.754	19	18
19. Project size ($)	0.669	0.749	25	19
20. Project driver (cost, schedule, quality, production)	0.719	0.727	24	20
21. Site location (remote, urban)	0.762	0.727	17	21
22. Project nature (grassroots, addition, modernization)	0.746	0.722	20	22
23. Work schedule (10/4, 5/2, etc.)	0.723	0.720	22	23
24. Percent work scheduled overtime	0.723	0.702	23	24
25. Worker accommodations (live in camp, LOA etc.)	0.642	0.702	26	25
26. Planning for startup	0.727	0.688	21	26
27. Contract type (fixed price, cost reimbursable, etc.)	0.565	0.654	32	27
28. System automation & Integration	0.627	0.629	28	28
29. Mode of travel to worksite (bus, plane, etc.)	0.612	0.624	30	29
30. Union workforce	0.635	0.612	27	30
31. Public regulation	0.615	0.588	29	31
32. Amount of subcontracted work	0.585	0.524	31	32
33. Offshore engineering	0.565	0.490	33	33

To ascertain whether the ranking of the 33 factors was significantly different between the U.S. and Alberta projects, a non-parametric Spearman's rank correlation was performed. The results of the Spearman correlation indicated a statistically high correlation between Alberta and U.S. experts, with r=0.942 and p=0.00, as shown in Figure 7.12.

Correlations

		Rank_U.S.	Rank_Alberta
Rank_US	Pearson Correlation	1.000	.942**
	Sig. (2-tailed)		.000
	N	33	33
Rank_Alberta	Pearson Correlation	.942**	1.000
	Sig. (2-tailed)	.000	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 7.12 Spearman Rank Correlation of Factors Impacting Construction Productivity Indicated by Alberta and U.S. Experts

The majority of the rankings shown in Table 7.5 are as expected because the impact factors are common to all large EMR projects. In particular, most of the top ten factors shown in Table 7.5 that impede productivity in Alberta are also experienced in the U.S. It should be noted that the t-test results provided in Table F.5 of Appendix F, reveal that the differences between the factors on U.S. and Alberta projects primarily exist in the degrees of impact. The overall results also indicate that Alberta projects tend to experience a higher degree of negative impacts than U.S. projects. The degrees of impact on Alberta projects were especially high on the *number of changes* and *labor skill*, as addressed in Section 7.3.1. This also explains the impact of weather conditions. Even though it was ranked at the same level by both Alberta and U.S. experts, the results consistently indicate the higher degree of negative impacts of weather conditions on Alberta projects than U.S.

7.4 VALIDATION OF FACTORS IMPACTING CONSTRUCTION PRODUCTIVITY

The ranking of the 17 factors impacting construction productivity from Alberta benchmarking dataset, as shown in Figure 7.6, was verified by analyzing the results from 41 Alberta expert opinion responses from the additional survey of project practitioners shown in Table 7.5. The impact factors from these two data sources were synchronized to align differing naming conventions. Subsequently, only 13 factors remained and were considered for validation in this section. Four factors were excluded because they were not ranked highly in either data source. The ranking of the 13 remaining factors are shown in Table 7.6.

Table 7.6 Comparison of Ranked Major Factors Affecting Field Productivity as Indicated from the Alberta Benchmarking Data and the Additional Survey

Factors	Ranked by BM data	Ranked by Additional Survey
Percent engineering completed before construction start	1	6
Business market condition	2	8
Quality of field supervision	3	1
Labor skill	4	5
Site conditions	5	4
Weather conditions	6	10
Project team experience	7	9
Project complexity	8	11
Material availability	9	2
Project team turnover	10	3
Labor availability	11	7
Amount of schedule overtime	12	12
Regulation requirements	13	13

The Spearman correlation, non-parametric statistic, was performed on the two sets of ranking factors under the expectation that the rank of the impact factors based upon the Alberta benchmarking dataset would be consistent with the rank specified by Alberta expert opinion from the additional survey. The Spearman correlation coefficient indicates the strength and direction of this consistency. Again, as is common practice in social science research, if r>0.5, the rank correlation is considered high, then the set of factors indicated by the project teams through Alberta benchmarking is justified and reliable for further analysis. The results of the Spearman correlation are tabulated in Figure 7.13.

Correlations

			Alberta_ Benchmarking Data	Alberta_ Additional Survey
Spearman's rho	Alberta_ Benchmarking Data	Correlation Coefficient	1.000	.534*
		Sig. (2-tailed)	.	.049
		N	13	13
	Alberta_ Additional Survey	Correlation Coefficient	.534*	1.000
		Sig. (2-tailed)	.049	.
		N	13	13

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 7.13 Spearman Rank Correlation to Validate Factors Impacting Field Productivity

The results shown above indicate a statistically moderate to high positive correlation between the two sets of rankings with a high correlation (r=0.534, p=0.05, N=13). The results indicate that there is a significant relationship between a set of factors impacting construction productivity identified by Alberta benchmarking dataset and by expert opinions from the additional survey. This positive correlation coefficient indicates the factor rankings are similar. Therefore, the author concluded that the 13 factors listed in Table 7.6 were acceptably reliable as major factors impacting construction productivity on Alberta projects. As a result, it can be concluded that analysis conducted on this set of factors will be reliable.

7.5 ANALYSIS OF RELATIVE IMPACT OF FACTORS ON FIELD PRODUCTIVITY

The purpose of this section is to establish the third hypothesis of this study. A more intensive analysis, as shown in Figure 7.14, was conducted to assess the relative impact of factors affecting Alberta project field productivity. All 17 factors impacting construction productivity as listed in Figure 7.6 were employed using the methodology shown in the shaded boxes below.

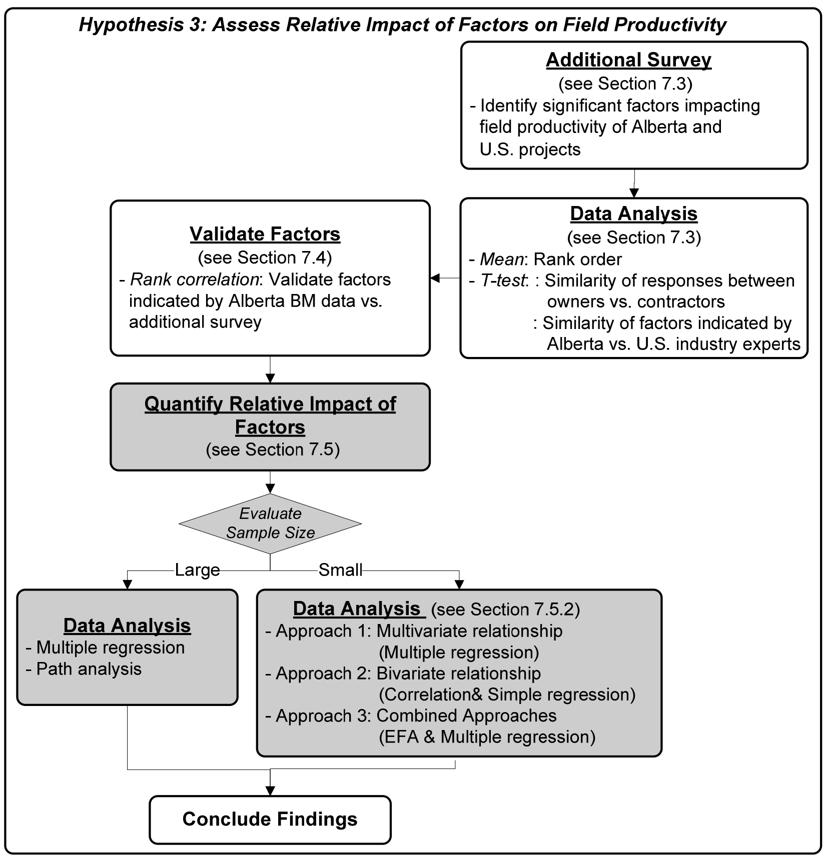


Figure 7.14 Analysis of the Third Hypothesis

Similar to Figure 7.6, again, these 17 factors are listed as follow:

Factors Impacting Construction Productivity Indicated by Alberta Dataset
1. Percent engineering completed before construction start
2. Amount of unplanned overtime
3. Business market conditions
4. Quality of field level supervision
5. Craft labor skill
6. Site conditions
7. Weather conditions
8. Percent engineering completed prior to project sanction
9. Project team experience
10. Project complexity
11. Material availability
12. Project team turnover
13. Engineering labor skills
14. Labor availability
15. Amount of scheduled overtime
16. Regulatory requirements
17. Coordination with plan shutdown

It is widely accepted that Alberta projects and other large EMR projects are subjected to a burden of adverse effects from factors such as severe weather, scarcity of skilled labor, and poor engineering quality. It would be most beneficial to quantify the impacts of a given factor while taking into account other variables. By studying the effects of one factor while holding all other factors constant, the exclusive impact of each factor can be determined. This way one can clearly identify which factor has a stronger effect on field productivity. These results provide hard data for a project team to adjust average productivity expectations by taking into account specific job conditions that are anticipated.

7.5.1 Evaluate Sample Size

The number of data in this analysis is based upon the number of responses for each factor listed in Section 6.3 of the Alberta benchmarking questionnaire, regarding project impact factors and the CPM index number for each project. Multiple regression (MR) analysis was selected as an approach to prove the third hypothesis. It is widely accepted that MR is appropriate for analysis of the relative importance among factors (Keith, 2005). The rule of thumb to determine the minimum number of data points required to perform a multiple regression is that one must have at least 10 to 20 data points for each independent variable studied. Accordingly, with 17 factors included in this study, a minimum of 170 to 340 project data points were needed. It should be noted, however, that this rule of thumb has not been formally validated. Instead as explained below, Keith (2005) recommended that the power of statistics results and effect size be considered to evaluate the sample size needed to achieve statistically significant results.

Power generally refers to the ability to correctly reject a false null hypothesis. The required sample size depends on the desired power, which is generally 0.8 or 0.9 (Cohen, 1988; Kraemer and Thiemann, 1987). Power numbers of 0.8 and 0.9 signify that the researcher desires an 80% or 90% chance of rejecting a false null hypothesis. The effect size is estimated from preliminary data analysis results and the designated alpha value. Effect size is a standardized measure of magnitude of the observed effect. Many measures of effect size have been used, but the most common are Cohen's d and Pearson's correlation coefficient r, or R^2 in terms of regression analysis (Field, 2005).

To calculate the sample size necessary to achieve a given level of power for multiple regression, this study chose an α level of 0.05 while estimating the effect size from a preliminary data analysis. The estimated effect size was examined by the results of the preliminary multiple regression which regressed the CPM index on 17 factors, as detailed in Appendix E.5. The most acceptable multiple regression results were produced by utilizing three factors which yielded an R^2 value of 0.35 with a sample size of 12 for each independent variable. This R^2 value referred to the estimated effect size to calculate the required sample size.

Figure 7.15 presents the results from G-power, a power analysis software, to evaluate the required sample size. The X-axis indicates the total sample size for the MR analysis, while the Y-axis represents power or present error of the analysis results. After performing calculations on the data from the preliminary MR, the effect size was 0.35, with 12 data records for each variable at α= 0.05, and G-power indicated a power of approximately 0.40 for this dataset. In order to produce more reliable analysis results, an objective power of at least 0.9 should be met. That is, the researcher would like to have a 90% chance of rejecting a false null hypothesis, so that a hypothesis with no relationship between predictors and dependent variables (R^2=0) is correctly rejected. It can be seen from Figure 7.15 that the results from G-power indicated that at least 30 data points in common for every variable is needed to reach a power of 0.9. The graph shows that the required power (0.8) was reached with approximately 30 data records for each variable.

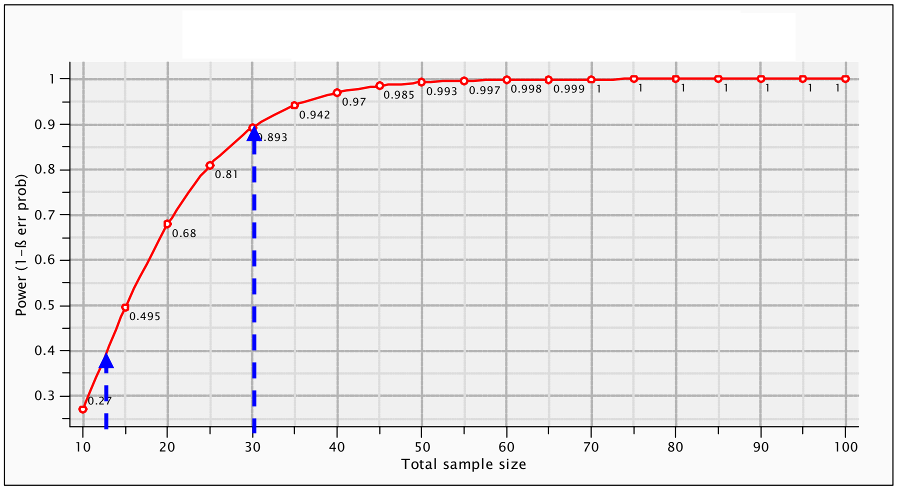


Figure 7.15 Power Curve for Multiple Regression of Alberta Dataset

Project teams struggle to assess the impacts of the 17 factors on construction productivity over the entire project duration. Consequently, it was difficult to attain a large sample size for each independent variable and the 37 Alberta-submitted projects could not provide sufficient data to perform the multiple regression analysis on all factors. Thus, another approach adapted to a small dataset was applied. The small sample size approach consisted of several bivariate and multivariate analyses to obtain evidence of the relative impacts among factors. Although the analyses cannot statistically support the third hypothesis, it is the belief of the author that the analysis results are still valuable and meaningful for the industry.

7.5.2 PROPOSED ANALYSES FOR RELATIVE IMPACT OF FACTORS

To analyze the small dataset, three analysis approaches were used by the author to provide evidence of the most significant impact factors on construction productivity. The first approach, multiple regression, was performed to illustrate the results that can be achieved when the sample size is large enough. The second approach employed a bivariate analysis to quantify the relative importance of each of 17 factors on the CPM index by considering their impacts by strength of correlations and the simple regression coefficients. The third approach is a combined analysis using an exploratory factor analysis to deal with the multicollinearity among factors and then determining the relative impact among groups of factors by using multiple regression. The detailed analyses of these three approaches are presented in the next sections.

Again, as mentioned in Section 7.1, the responses regarding the degree of impact of the 13 factors are on a nominal scale ranging from -2 to +2, which indicates “high negative impact” ranging to “high positive impact”. To enhance the analysis presented in this section, this degree of impact scale was converted to a scale of 5 to 1, with 5 indicating “high negative impact” and 1 indicating “high positive impact.”

7.5.2.1 Test Assumptions for Pearson’s Correlation and Simple Regression

Prior to conducting Pearson’s correlation and regression procedures, 17 factors and the construction productivity project level index (CPM index) were examined to ensure that the underlying assumptions were justified. A sample data source consisting of 37 projects was submitted through the Alberta benchmarking system. Varying responses were recorded per impact factor, from 4 data points for one impact factor, to 23 on another, as shown in Appendix E.5. The assumption of the independence of each observation was accepted since project data were submitted by different companies. Inspection of the data using the Normal Q-Q plots indicated reasonably normal distributions every impact factor. Next, linear relationships among variables were investigated by producing scatter plots between the CPM index and the 17 impact factors. The majority of results were shown to be acceptable as linear relationships. Although some relationships among these factors address violations of linearity and homoscedasticity of errors, the analyses of these factors were performed nonetheless in order to illustrate the procedure. When more data are collected, more robust the analyses will be available. At this point, the results should be interpreted with caution due to the violations of linearity and homoscedasticity of errors and a small sample size. The detailed statistical tests are presented in Appendix E.5.

7.5.2.2 Approach 1: Multiple Regression

The first approach was to perform stepwise multiple regression to quantify the relative impact among factors on the CPM Index. More data analysis results are provided in Appendix E.5. In this section, the 17 impact factors are converted to the same scale, which is a nominal scale ranging from 5 to 1. Five indicates a “high negative impact” and 1 indicates a “high positive impact.” The multiple regression coefficient is then used to compare the relative influence of a particular factor on field productivity. The assumptions for the multiple regression analysis (independence of the sample, linearity, and normality) were met, as described earlier. However, due to a high multicollinearity among the 13 factors indicated by correlation analysis, a stepwise multiple regression should be used to determine the significant factors impacting construction productivity. The analysis results are as shown in Figure 7.16.

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.912[a]	.831	.789	.27798	.831	19.737	1	4	.011	
2	.987[b]	.974	.957	.12523	.143	16.710	1	3	.026	1.663

a. Predictors: (Constant), actegconp

b. Predictors: (Constant), actegconp, overconp

c. Dependent Variable: CPM_Index

ANOVA[c]

Model		Squares	df	Mean Square	F	Sig.
1	Regression	1.525	1	1.525	19.737	.011[a]
	Residual	.309	4	.077		
	Total	1.834	5			
2	Regression	1.787	2	.894	56.982	.004[b]
	Residual	.047	3	.016		
	Total	1.834	5			

a. Predictors: (Constant), actegconp

b. Predictors: (Constant), actegconp, overconp

c. Dependent Variable: CPM Index

Coefficients[a]

Model		Unstandardized Coefficients: B	Std. Error	Standardized Coefficients: Beta	t	Sig.	Collinearity Statistics: Tolerance	VIF
1	(Constant)	-2.848	.520		-5.477	.005		
	Percent eng. completed before construction start	.676	.152	.912	4.443	.011	1.000	1.000
2	(Constant)	-4.195	.404		-10.376	.002		
	Percent eng. completed before construction start	.632	.069	.851	9.091	.003	.975	1.026
	Scheduled overtime	.449	.110	.383	4.088	.026	.975	1.026

a. Dependent Variable: CPM Index

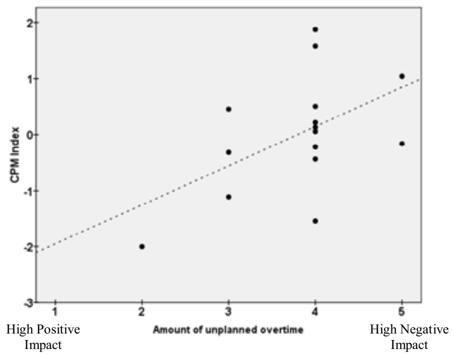
Figure 7.16 Approach 1- Ranking the Relative Impact of Factors by Using Multiple Regression

As can be seen in Figure 7.16, the results of the regression produce a high *R*-squared value (R^2=0.974, *p*=0.00, *N*=6) which surprisingly, is significant with only 6 data points. The *percent of engineering completed before construction start* and the *amount of scheduled overtime* were the only two factors selected by stepwise multiple regression. These two factors together account for 97% of the variation in construction productivity. By comparing multiple regression coefficients, it can be concluded that the *percent of engineering completed before construction start* has a larger impact on Alberta project field productivity than the *amount of scheduled overtime*. This finding is aligned with the inferential statistical results found in Chapter 6, as well as the industry opinions described in Chapter 7. Experts strongly agree that engineering that is more complete has a strong beneficial impact on field productivity. A more complete design leads to fewer changes and reduced waiting time for requested information and materials. Further analysis on a larger sample is warranted; however, when more data are available, these results are only provided to illustrate the technique, not the results.

7.5.2.3 Approach 2: Bivariate Relationship

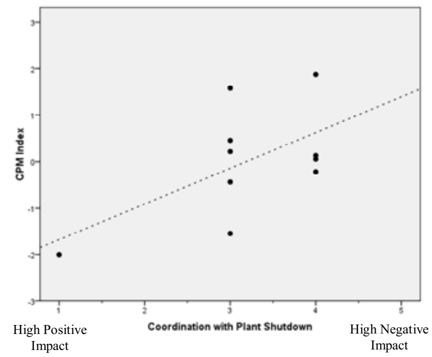
In the bivariate approach, each of the 17 factors and the CPM index were analyzed by using the Pearson's correlation followed by a simple regression. This method of analysis considers bivariate relationships for consistency with approaches 1 and 3 which will follow. The results lack a sound statistical basis because there are multiple factors influencing productivity and this analysis only considered bivariate relationships. The author expected a positive correlation and regression slope between the 17 factors and the CPM index due to the scoring approach adopted in this research. This means the more negative the impact on a project, the lower the expected productivity. The analysis results are as shown in Figure 7.17.

Amount of unplanned overtime



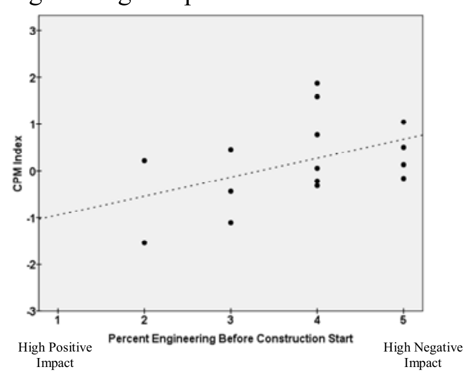
Y= 0.699X-2.651, R^2=0.263, *p*=0.05, *N*=15

Coordination with plant shutdown



Y= 0.767X-2.443, R^2=0.346, *p*=0.074, *N*=10

Percent engineering completed before construction start



Y= 0.405X-1.347, R^2=0.202, *p*=0.092, *N*=15

Figure 7.17 Approach 2- Ranking the Relative Impact of Factors by Considering Bivariate Relationship

Table 7.7 provides a summary of Pearson's correlation coefficients and simple regression coefficients conducted on each factor with the CPM index. The 17 factors are ranked by considering both the correlation significance and the magnitude of the simple regression slope, from highest to lowest. The results indicate the highest correlation and regression slope for *coordination of plant shutdown*. However, this approach considers statistical significant results for the correlation and the relatively steeper regression slope. The *amount of unplanned* *overtime* was ranked as the highest influencing factor on Alberta project field productivity with r=0.51, slope=0.699, and a low R-squared value (R^2=0.263, p=0.05, N=15). The second and third ranked factors are the *coordination of plant shut down* and the *percent of engineering completed before construction start*, but the results are not statistically significant. The author again acknowledges that direct ranking of the factors based on simple bivariate analyses does not follow sound statistical techniques. It is merely provided here as an investigative step looking for consistency in factors among the approaches.

Table 7.7 Approach 2- Relative Impact of Factors by Considering the Bivariate Relationship

Rank by Slope	Factors	Statistical Results
1	Amount of unplanned overtime	N=15, r=0.51*, slope=0.699
2	Coordination with plant shutdown	N=10, r=0.59 , slope=0.767
3	Percent engineering completed before construction start	N=15, r=0.45 , slope=0.405
4	Amount of scheduled overtime	N=14, r=0.34, slope=0.618
5	Material availability	N=19, r=0.33 , slope=0.577
6	Project complexity	N=19, r=0.38 , slope=0.569
7	Project team experience	N=17, r=0.35 , slope=0.492
8	Percent engineering completed prior to project sanction	N=11, r=0.32 , slope=0.375
9	Engineering labor skill	N=10, r=0.28 , slope=0.420
10	Quality of field level supervision	N=17, r=0.34 , slope=0.337
11	Weather conditions	N=17, r=0.23 , slope=0.252
12	Business market conditions	N=14, r=0.07 , slope=0.075
13	Labor availability	N=19, r=0.02 , slope=0.020
14	Regulatory requirements	N=16, r=-0.10 , slope=-0.288
15	Craft labor skill	N=22, r=-0.02 , slope=-0.015
16	Site conditions	N=21, r=-0.193, slope=-0.273
17	Project team turnover	N=15, r=-0.100, slope=-0.142

Note: * indicates significance of test statistics at α level =0.05
N represents a number of data for each factor and CPM index associated with the analysis
r is the Pearson's correlation. Slope is the simple regression coefficient

7.5.2.4 Approach 3: Factor Analysis and Multiple Regression

The third approach was to apply factor analysis and multiple regression to quantify the impact of each factor on CPM index. Due to the strong correlation evidence between the 13 factors (or multicollinearity among independent variables), some factors were grouped by using factor analysis in order to avoid producing unstable coefficients in multiple regression. The factors were grouped by using the Exploratory Factor Analysis (EFA), which is a data reduction technique used to identify a number of latent variables constructed from a large number of observed interrelated variables. Then, through principal components analysis, which is a common EFA technique with oblique rotation, the factors were extracted. A detailed explanation of EFA is provided in Appendix E.5.

As the results show in Figure 7.18, factors 1, 2, 3 and 4 demonstrated eigenvalues greater than one, which is consistent with a result of the scree plot. Also, based on Kaiser's rule, the first four constructed factors were considered meaningful and were retained with an ability to account for approximately 94% of the common variance. Due to a high correlation between these four constructed factors, an oblique rotation was performed to obtain a simple structure. The simple structure indicated by EFA suggested a loading of each impact factor on each constructed factor as shown below.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.343	52.449	52.449	7.343	52.449	52.449	4.613	32.950	32.950
2	2.701	19.296	71.745	2.701	19.296	71.745	3.632	25.944	58.894
3	2.068	14.771	86.516	2.068	14.771	86.516	2.814	20.101	78.995
4	1.087	7.768	94.283	1.087	7.768	94.283	2.140	15.288	94.283
5	.800	5.717	100.000						
6	4.920E-16	3.514E-15	100.000						
7	1.687E-16	1.205E-15	100.000						
8	7.987E-17	5.705E-16	100.000						
9	4.048E-18	2.891E-17	100.000						
10	-5.189E-17	-3.706E-16	100.000						
11	-1.155E-16	-8.248E-16	100.000						
12	-4.168E-16	-2.977E-15	100.000						
13	-7.412E-16	-5.294E-15	100.000						

Extraction Method: Principal Component Analysis.

Pattern Matrix[a]

Variables	Component 1	2	3	4
Weather condition	.272	-.012	.313	.904
Labor skill	.671	-.014	-.400	.185
Labor availability	.533	-.319	-.353	.259
Material availability	.723	-.048	-.376	.238
Site condition	.067	.013	-1.022	-.183
Project complexity	.162	-.720	-.105	.339
Regulatory requirement	.308	-.849	.385	-.039
Project team experience	.373	.159	-.579	.374
Project team turnover	.019	-.211	-.665	.488
Quality of field supervision	.854	-.198	-.149	.088
Amount of scheduled overtime	.349	.787	.261	.460
Amount of unplanned overtime	-.227	.042	-.152	1.008
Percent engineering before construction start	1.016	-.096	.267	-.221

Figure 7.18 Approach 3- Group Impact Factors by Factor Analysis

From the EFA results, the 13 factors were grouped into four constructed factors based upon the factor loading as shown in Figure 7.18. A summary of factor assignments is shown in Table 7.8.

Table 7.8 Constructed Factors Grouped by EFA

Constructed Factors	Impact Factors
Factor 1: Availability of information and resources for execution	Labor skill
	Labor availability
	Material availability
	Experience of site supervision
	Percent engineering completed before project start
Factor 2: Project complexity	Project complexity
	Regulatory requirements
	Amount of scheduled overtime
Factor 3: Team experience	Site conditions
	Project team experience
	Project team turnover
Factor 4: Unexpected conditions	Weather conditions
	Amount of unplanned overtime

Next, the author regressed CPM index on the four constructed factors by using a stepwise multiple regression. Again the regression coefficient of each factor was compared to indicate which factors had the largest impacts on field productivity. As the results show in Figure 7.19, only the first factor was selected. Factor 1, availability of information and resources for execution, was found to be a statistically significant predictor of CPM index with R^2=0.30, p=0.02, N=19. In addition, t-statistics indicate statistical significance of the regression coefficient with p=0.02. It can be concluded that factors related to the availability of information and resources for execution have a statistically significant effect on Alberta field productivity over the other three constructed factors.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.544[a]	.296	.254	.86094	.296	7.134	1	17	.016	2.438

a. Predictors: (Constant), Factor1

b. Dependent Variable: CPM_delout

ANOVA[b]

Model	Sum of Squares	df	Mean Square	F	Sig.
1 Regression	5.288	1	5.288	7.134	.016[a]
Residual	12.601	17	.741		
Total	17.889	18			

a. Predictors: (Constant), Factor1

b. Dependent Variable: CPM_delout

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
1 (Constant)	-2.156	.807		-2.672	.016		
Factor1	.117	.044	.544	2.671	.016	1.000	1.000

a. Dependent Variable: CPM_delout

Figure 7.19 Approach 3- Impact Factor Results from Multiple Regression

In summary, the results from the three analyses provided complementary evidence that the percent of engineering completed before construction start has the most significantly strong impact on Alberta field labor productivity compared to other factors in this study. In other words, even though a project has a highly-skilled work force, workable weather conditions, material availability on site, etc., the project field productivity will likely suffer if engineering was not sufficiently completed prior to construction execution. However, it should be noted that more data are necessary to produce robust statistical results.

7.6 CHAPTER SUMMARY

Like any project, there is an array of factors affecting Alberta project performance. From the subjective assessments made by project teams who submitted projects in the Alberta benchmarking system developed in this study, this research has revealed a number of top factors affecting cost, schedule and productivity variance as shown in Figures 7.4 to 7.6. A the top five factors impacting project cost growth, schedule growth, and construction productivity as presented in Figure 7.4 to 7.6 were summarized in Table 7.9.

Table 7.9 Top Factors Affecting Cost, Schedule, and Productivity- Assessment from Alberta Benchmarking Data

Rank	Cost	Schedule	Productivity
1	Amount of Unplanned Overtime	Percent of Engineering Completed Prior to Construction Start	Percent of Engineering Completed Prior to Construction Start
2	Percent of Engineering Completed Prior to Construction Start	Business Market Conditions	Amount of Unplanned Overtime
3	Business Market Conditions	Craft Labor Skill	Business Market Conditions
4	Craft Labor Skill	Quality of Field Level Supervision	Quality of Field Level Supervision
5	Coordination with Plant Shutdown	Weather Conditions	Craft Labor Skill

These factors were indicated based upon the subjective assessment from the project teams submitted in the Alberta benchmarking database The *amount of unplanned overtime* was found to have the most significant impact on project cost. The existence of unplanned work can be driven by such causes as unexpected delay due to severe winter weather, work due to major changes, a lack of material, equipment, and labor, poor planning or unexpectedly low productivity. In terms of project schedule, the *percent engineering completed before construction start* is the most significant impact factor.

Ultimately, the most significant factors impacting construction productivity according to expert opinion were quantitatively analyzed. After considering the analysis results from the Alberta benchmarking database, additional survey, and quantitative analysis on relative impacts of factors, it appears that the *percent of engineering completed before construction start* is an important factor that strongly and directly impacts field productivity.

Field productivity is emphasized because it contributed to schedule delay in part, causing project cost overrun. Because of the small sample size, the multiple regression analysis necessary to properly establish the third hypothesis is not viable. Due to the mega size of Alberta projects, a large number of data points is difficult to obtain. Nevertheless, this study used three analysis approaches to analyze the limited dataset. Altogether, these three approaches independently indicated evidence that *the percent of engineering completed before construction start* is a significant factor impacting Alberta field productivity. Also, the results from the factor analysis (Approach 3) show that *percent of engineering completed before construction start* is included in the group of factors with the highest impact on construction productivity (Group 1: Availability of information and resources for construction execution).

The analysis results described in this section were presented to more than 50 industry experts during the COAA benchmarking committee and COAA board meetings, and the meeting attendees reached a consensus that the impact factors are valid. This judgment was made based upon their experiential knowledge and their scrutiny of the scientific results presented before them. Overall, it can be seen from the results that the root causes of cost overrun, schedule delay and low construction productivity include management practices (e.g. *percent engineering completed before construction start*, *planning for overtime*), not environmental factors (e.g. *site conditions*, *weather* or *regulatory requirements*).

CHAPTER 8:
CONCLUSIONS AND RECOMMENDATIONS

This chapter completes this research by providing conclusions derived from this research. The achievement of the research objectives are reviewed, followed by a discussion of the results and support for the research hypothesis. Then, the research contributions are discussed and recommendations for future research are presented.

8.1 REVIEW OF RESEARCH OBJECTIVES AND CONCLUSIONS

The main purpose of this research was to quantitatively assess the performance of capital large EMR projects in Alberta and identify the root causes of project performance problems and ineffective field productivity. Specific objectives of this research include:

1) Develop metrics and a performance measurement system customized to challenges of Alberta
2) Establish a project performance reporting system that provides valuable information that meets the needs of industry
3) Demonstrate the differences of field productivity and overall project performance between Alberta and U.S. projects
4) Examine the relationships between project characteristics, practices, productivity and overall project performance
5) Identify factors impacting field productivity of Alberta projects

6) Assess the relative impact of significant factors impacting field productivity of Alberta projects

8.1.1 Develop metrics and performance measurement system for large EMR projects customized to the challenges of Alberta

While it is not possible to obtain measures for every aspect of project performance, this study does provide a broad range of metrics necessary to gain new insights into Alberta's heavy industry sector projects. A set of metrics and data elements specific to key issues in Alberta such as workforce, indirect cost, unit cost and productivity estimation were added and integrated into the CII large projects benchmarking system. This led to the programming of a customized web-based data collection instrument. A list of these metrics developed for Alberta projects was described in Chapter 3 and 4. The creation and validation of these additional developments were affirmed over a series of meetings over three years between COAA's benchmarking committee and the CII BM&M staff.

8.1.2 Establish a Project Performance Reporting System

The CII benchmarking key report was customized for Alberta based projects based on a series of workshops and teleconferences with the COAA benchmarking committee. The key report developed for COAA provides feedback of the project's performance with comparisons to other similar projects in the Alberta benchmarking database. An important feature of the developed system is the comparison of estimated productivity and unit cost with the actual database mean at sanction. The report summarizes metrics by presenting scores, as well as database means, performance quartiles, and sample sizes from the most comparable dataset. The

COAA and CII teams collaboratively defined the benchmarking algorithms to mine the database as provided in Section 4.3. Over a series of meetings, the Alberta industry experts affirmed the value of the report that helps them identify the gaps in performance. Moreover, they used the information contained within the key reports to communicate knowledge gained about their projects in order to improve key work processes. Continued use of the benchmarking process should generate improved intelligence and ultimately supports project improvement.

8.1.3 Demonstrate Differences of Overall Project Performance between Alberta and U.S. Projects

A number of comparisons of project performance including engineering and construction productivity were made between Alberta projects and relatively similar U.S. projects, resulting in a number of important findings. Before conducting this study, it was perceived that Alberta projects had a much lower productivity compared to U.S. projects. However, the results in this research which are still preliminary indicate that Alberta projects are approximately as productive as U.S. projects at some discipline levels as measured by direct engineering and construction labor productivity. Also, scope, development changes, and quality, as measured by rework, are in line with that of U.S. projects. The results of the preliminary data analyses also reveal that Alberta projects may have a comparatively high proportion of indirect cost to total project cost. Construction indirect cost accounts for roughly 20% of the total project cost, and 34% of the direct work hours. This is caused by remote jobsites, extreme weather and underestimating of productivity rate and number of peak workforce. Again, given the differences in project environments and challenging factors, this study acknowledges that these two groups of project face very different challenges. As a result, the analysis in this section is intended to examine project performance of the Alberta projects caused by their challenging environments, and is not intended to identify which group yields superior project performance.

8.1.4 Examine the relationships between project characteristics, practices, productivity and overall project performance

Analyses in Chapter 5 and 6 suggested that Alberta projects typically overestimate their direct productivity, yet underestimate their installed unit cost. This overestimation problem is compounded by much higher amounts of indirect labor and cost required for Alberta projects, when compared to U.S. projects. Taken together, the underestimation of total labor required yielded significant resource peaks much higher than estimated which showed strong correlations with adverse project cost growth. Therefore, predictability in estimating and project management is needed. As shown by the analysis, the appropriate time to start construction (somewhere around 65% to 70% of engineering completion) may dramatically reduce construction cost growth. Also, greater implementation of management best practices such as project risk assessment, planning for startup, and constructability are observed to be beneficial on project performance improvement. Indeed, it is clear that improvement is needed in management-related aspects of planning, estimating, and controlling work.

8.1.5 Identify Factors Impacting Field Productivity of Alberta Projects

The array of factors affecting project cost, schedule and productivity performance is presented in Chapter 7. By using a series of surveys of benchmarking participants, this research identified some important factors impacting project cost, schedule, and construction productivity. This research also found that the top factors affecting cost, schedule and productivity vary, but show some consistency. From management's perspective, the major causes of poor performance are related to manage practices rather than environmental factors. Ultimately, the detailed analysis on field productivity by using Alberta benchmarking data provides the evidence that *percent complete of engineering before construction start* is perhaps the most significant factor affecting field productivity.

8.2 REVIEW OF RESEARCH HYPOTHESIS AND CONCLUSIONS

The research hypotheses presented in Section 1.3 are listed below with review and conclusions drawn from this study:

Hypothesis 1: Metrics for measuring project performance specific to challenging environments for Alberta projects can be developed and assessed.

The Alberta benchmarking questionnaire and data collection system were developed from a series of extensive discussions and provided a reliable data collection system by feedback from industry experts. The metric distributions and data analysis results are presented in Chapters 5 and 6. When reviewed by the industry experts, scores of each metrics were deemed to be meaningful, understandable, and quantifiable measures suitable for assessing Alberta project performance. The data are being captured with sufficient accuracy and consistency to assess a broader range of data necessary to gain new insights into Alberta's heavy industrial sector projects. Moreover, industry experts affirmed that the key report and data analysis results provide them valuable information and drives the appropriate action to improve their work process.

Hypothesis 2: Factors impacting project performance and productivity can be identified.

This research identified some potential factors affecting project cost, schedule, and engineering and construction productivity performance of Alberta projects. The impacts of eighteen factors were assessed and ranked by their average degree of influence on cost, schedule and construction productivity as the results provided in Section 4.7. Further investigation on construction productivity, factors were cross validated with industry expert opinion and the analysis results affirms the validity of the factors.

Hypothesis 3: The relative impact of factors which influence Alberta project field productivity can be assessed.

Preliminary analyses of the relative impacts of factors on construction productivity are presented in Section 7.4. Three approaches for data analyses were introduced. The initial results from the three analyses provided complementary support that the *percent engineering completed before construction start* may have the most important strong impact on construction productivity on Alberta projects. This result is also in conformance with the conclusion drawn by inferential analysis in Chapter 6, as well as industry expert opinions.

8.3 RESEARCH CONTRIBUTIONS

The primary contributions of this research was to develop quantitative project performance assessments and industry wide benchmarking that can indicate the potential root cause of performance problems for heavy industrial sector capital projects in Alberta. In many ways, this study confirms the lessons of previous studies; whereas this study ultimately creates an improved awareness and adds to the abilities of Alberta-based companies and personnel to manage the unique projects found in Alberta. Major contributions of this research include:

1) Established metrics and project performance norms tailored to Alberta-based projects.
2) Initiated standardized industry-wide benchmarking for heavy industry sector in Alberta.
    a. Developed a questionnaire with consensus definitions.
    b. Expanded capability of the data collection system.
    c. Developed an intensive project benchmarking summary report.
    d. Provided a hierarchical structure of project types to produce reasonable benchmarks.
3) Developed framework for data collection with a broad range of data necessary to gain new insights into the results of Alberta's heavy industry sector projects e.g. cost, schedule, safety, workforce, engineering and construction productivity, and impact of factors.
4) Provided methodology and preliminary quantitative assessment of project performance differences between Alberta and U.S. projects.
5) Provided preliminary indications of the relationships between project management strategies and performance to support understanding of the

benefits obtained through best practice use in the management of capital projects.

6) Identified some important factors impacting project performance and productivity on large EMR projects and provided the path forward for quantitative analysis of impact of factors
7) Preliminarily revealed key issues affecting project performance in Alberta and the drivers for improved capital project performance, especially in the areas of planning, estimating, and productivity

8.4 RECOMMENDATIONS FOR FURTHER RESEARCH

While the metrics, performance measurement and benchmarking system was validated through expert opinion and data analysis, there still remain significant questions that warrant further research. Achieving these answers require continuous data collection within this benchmarking activity. This study holds important possibilities for further research in two potential areas.

The first recommended enhancement is to improve the benchmarking system and questionnaire in capturing additional issues from the findings drawn by this research. A number of metric definitions require refinement, such as construction indirect cost and work hours, changes and total cost of modules, which were found to be primary factors causing cost increase. For instance, the construction indirect work for building the site facilities and indirect work to support work packaging should be segregated to enhance analysis on productivity improvement. Other issues also include expanding metrics to measure productivity of offsite modularization and other prefabricated modules. Further research could provide more compelling results when more data are available. In addition, analysis can be conducted to measure an advantage of managing mega projects as multiple smaller projects as well as identifying more manageable project sizes. The distinctive value of implementation each best practice should also be quantitatively assessed to help the project team prioritize their management focus area for enhancement.

Further research and continued data collection to support the benchmarking system developed in this study is recommended. A larger sample size will enable a trend analysis on Alberta project performance and productivity improvement. Moreover, a larger sample size will provide the potential to perform data analysis by considering the impact of multivariable factors on project performance and productivity.

Another area of enhancement lies in making a continuous effort in developing a project performance and productivity estimating tool that takes into account various project characteristics, and management strategies of projects under the affect of different project environments. This tool could be developed by incorporating the impact of implementation of construction practices, management strategies, project characteristics, and impact of environmental factors to anticipate project cost, schedule and productivity performance. The anticipated results will help project teams develop their project execution plan when projects experience environments and situations when there is no historical project data in the internal company database to provide valuable information.

Appendices

Appendix A: Glossary of Terms

General Terms

Addition (Add-on) – A new addition that ties in to an existing facility, often intended to expand capacity.

Grass Roots, Green Field – A new facility from the foundations and up. A project requiring demolition of an existing facility before new construction begins is also classified as grass roots.

Modernization, Renovation, Upgrade– A facility for which a substantial amount of the equipment, structure, or other components is replaced or modified, and which may expand capacity and/or improve the process or facility.

Percent Offsite Construction Labor Hours– The level of offsite labor hours for building modules. This value should be determined as a ratio of the offsite labor hours of all modules divided by total construction hours.

Rework– is defined as activities in the field that have to be done more than once in the field or activities which remove work previously installed as part of project.

Total Construction Hours – The summation of all direct and indirect hours associated with the construction phase.

Project Delivery System

Design-Bid-Build– Serial sequence of design and construction phases; Owner contracts separately with designer and constructor.

Design-Build (or EPC) – Overlapped sequence of design and construction phase; procurement normally begins during design; owner contracts with Design-Build (or EPC) contractor.

CM at Risk– Overlapped sequence of design and construction phases; procurement normally begins during design; owner contracts separately with designer and CM at Risk (constructor). CM holds the contracts.

Multiple Design-Build– Overlapped sequence of design and construction phases; procurement normally begins during design; owner contracts with two Design-Build (or EPC) contractors, one for process and one for facilities.

Parallel Primes– Overlapped sequence of design and construction phases; Procurement normally begins during design. Owner contracts separately with designer and multiple prime constructors.

Cost Definition

Construction Costs– include the costs of construction activities from commencement of foundation or driving piles to mechanical completion. The costs include construction project management, construction labor, and also equipment& supplies costs that are used to support construction operations and removed after commissioning. See "Instruction for Construction Direct and Indirect Costs" for detail of typical cost element.

Contingency– Contingency is defined as an estimated amount included in the project budget that may be required to cover costs that result from project uncertainties. These uncertainties may result from incomplete design, unforeseen and unpredictable conditions, escalation, or lack of project scope definition. The amount of contingency usually depends on the status of design, procurement and construction, and the complexity and uncertainties of the component parts of the project.

Direct Costs– Direct costs are those which are readily or directly attributable to, or become an identifiable part of, the final project (e.g., piping labor and material) [AACE].

Direct Cost of Field Rework– The sum of those costs associated with actual performance of tasks involved in rework. Examples include: Labor, Materials, Equipment, Supervisory personnel, Associated overhead cost.

Modularization– Modularization refers to the use of offsite construction. For the purposes of the benchmarking data, modularization includes all work that represents substantial offsite construction and assembly of components and areas of the finished project. Examples that would fall within this categorization include:

- Skid assemblies of equipment and instrumentation that naturally ship to the site in one piece, and require minimal on-site reassembly.
- Super-skids of assemblies of components that typically represent substantial portions of the plant, intended to be installed in a building.
- Prefabricated modules comprising both industrial plant components and architecturally finished enclosures.

Modularization does not include offsite fabrication of components. Examples of work that would be excluded from the definition of modularization include:

- Fabrication of the component pieces of a structural framework
- Fabrication of piping spool-pieces

Indirect Costs – Indirect costs are all costs that cannot be attributed readily to a part of the final product (e.g., cost of managing the project) [AACE].

Schedule Definition

Project Sanction – is defined as the milestone event at which the project scope, budget, and schedule are authorized. Project Sanction is the start of the execution phase of the project.

Commissioning and Startup – The transitional phase between construction and commercial operations; major steps include turnover, checkout, commissioning, and initial operations. Commissioning is the integrated testing of equipment and facilities that are grouped together in systems prior to the introduction of feedstocks.

Detail Engineering – Detail engineering is the project phase initiated with a contract to the firm providing detail engineering for the project. The typical activities included in this phase are: preparation of drawings, specifications, bill of materials, development of a definitive cost estimate, technical reviews, and engineering procurement functions. The detail engineering phase terminates with release of all approved drawings and specifications for construction.

Mechanical Completion– The point in time when a plant is capable of being operated although some trim, insulation, and painting may still be needed. This occurs after completion of pre commissioning.

Changes Definition

Change– A change is any event that results in a modification of the project work, schedule or cost. Owners and designers frequently initiate changes during design development to reflect changes in project scope or preferences for equipment and materials other than those originally specified. Contractors often initiate changes when interferences are encountered, when designs are found to be not constructable, or other design errors are found.

Change Order– A contractual modification executed to document the agreement and approval of a change (See definition of Change above).

Project Development Changes – Project Development Changes include those changes required to execute the original scope of work or obtain original process basis. Examples include:

1) Unforeseen site conditions that require a change in design / construction methods
2) Changes required due to errors and omissions
3) Acceleration
4) Change in owner preferences
5) Additional equipment or processes required to obtain original planned throughput
6) Operability or maintainability changes. (See Change above)

Scope Changes – Scope Changes include changes in the base scope of work or process basis. Examples include: 1) Feedstock change, 2) Changed site location, 3) Changed throughput, 4) Addition of unrelated scope

Engineering Productivity

Engineering Direct Work hours - should include all detailed design hours used to produce deliverables including site investigations, meetings, planning, constructability, RFIs, etc., and rework. Specifically exclude work hours for operating manuals and demolition drawings.

Engineering work hours reported should only be for the categories requested and may not equal the total engineering work hours for the project. (See "Instructions for Computation of Work hours and Rework-Hours" reference table)

Exclude the following categories: architectural design, plumbing, process design, civil/site prep, HVAC, insulation and paint, sprinkler/deluge systems, etc. Within a category, direct work hours that cannot be specifically assigned into the provided classifications, and have not been excluded, should be prorated based on known work hours or quantities as appropriate.

IFC Drawing– Issued for Construction drawings.

Construction Productivity

Actual Quantities and Work hours - are all quantities and work hours of actual installation and include rework hours for these quantities and work hours.

Estimated Productivity – are the estimated productivity of direct labor work hours required for installation according to the estimated quantity.

- **For owners**: Estimated Quantity, Work hours and Total Installed Unit Cost at the time of Project Sanction (or as soon as available following sanction)
- **For contractors**: Estimated Quantity, Work hours and Total Installed Unit Cost used as the basis of Contract Award.

Estimated Quantities and Work hours – are the estimated quantity to be installed, the estimated work hours required for the installation and include all change orders.

Estimated Total Installed Unit Cost – including labor and material cost at the time of project sanction (or as soon as available following sanction).

Estimated Total Installed Unit Costs **(TIUC)** – is the burdened direct cost of labor, material and equipment by pro rata share which are directly attribute to, or become a part of the final product including overhead and profit at the time of project sanction (or as soon as available following sanction).

Actual Total Installed Unit Costs **(TIUC)** – the burdened direct cost of labor, material and equipment by pro rata share which are directly attribute to, or become a part of the final product including overhead and profit from both direct hire and subcontract.

- The direct labor costs are considered as the costs of the labors listed as Direct in the *"Instructions for Computation of Actual Work Hours, Rework-Hours, and Installed Costs"* table in Construction Productivity Section.

Description of Project Impact Factors
(as listed in the Alberta Questionnaire in Section 6.3)

No.	Project Impact Factors	Description
1	Weather	This factor will distinguish the effect on productivity of differing weather conditions such as precipitation, wind, extremes of temperature, humidity, snow, etc.
2	Labor Skill	The influence of the level of skill and knowledge of workers and superintendent is captured by this factor.
3	Labor Availability	Whether the project is available to hire appropriate workers from the project region may affect productivity.
4	Materials Availability	This factor will indicate the level of impact on productivity by materials availability like tool and equipment availability, transporting of materials, timing for bulk materials, disruption by materials, and quality of materials.
5	Site Conditions	This factor will analyze the effect of soil conditions, site access, underground utilities, utilities (water, electrical) availability on site, etc.
6	Project Complexity	The influence of differing project complexity on the productivity is captured by this factor.
7	Regulatory Requirements	This factor accounts for regulatory requirements like health and safety requirements (OSHA), construction permits, local codes, government inspections, environmental protection agency (EPA), etc.
8	Project Team Experience	Experienced and knowledgeable superintendent and experienced crew, and experienced management may impact on productivity.
9	Project Team Turnover	The level of project team turnover during construction may impact on productivity due to transition, training, communication, and labor relationship.
10	Detailed Engineering Design Location	This factor accounts for any difficulties encountered due to the offshore design and design/drawing availability.
11	Business Market Conditions	The business market conditions like economic conditions and marketing my effect on productivity.
12	Coordination with Plant Shutdown	This factor accounts for the need for plant shutdown and the impact of plant shutdown during construction.
13	Quality of Field Level Supervision	This factor will indicate the level of impact on productivity by experienced and knowledgeable field supervisors may impact on productivity.
14	Amount of Schedule Overtime	This factor will analyze the effect of planned work overtime on labor productivity.
15	Amount of Unplanned Overtime	This factor will analyze the effect of overtimes which is not expected
16	Engineering Labor Skills	This factor will indicate the influence of the level of skill and knowledge of engineering labor to produce usability, complete and accurate of the engineering deliveries on productivity.
17	Percent Engineering Completed Prior to Project Sanction	This factor will indicate the influence of the level of completeness of engineering at project sanction on productivity.
18	Percent Engineering Completed Before Construction Start	This factor will indicate the influence of the level of completeness of engineering at project completion on productivity.

Appendix B: Metric and Project Phase Definitions

Performance Metric Formulas and Definitions

Performance Metric Category: COST

Metric: ***Project Cost Growth***	**Formula:** $\dfrac{\text{Actual Total Project Cost - Initial Predicted Project Cost}}{\text{Initial Predicted Project Cost}}$
Metric: ***Delta Cost Growth***	**Formula:** $\lvert \text{Cost Growth} \rvert$
Metric: ***Project Budget Factor***	**Formula:** $\dfrac{\text{Actual Total Project Cost}}{\text{Initial Predicted Project Cost +Approved Changes}}$
Metric***: Delta Budget Factor***	**Formula:** $\lvert \text{1- Budget Factor} \rvert$
Metric: ***Phase Cost Factor***	**Formula:** $\dfrac{\text{Actual Phase Cost}}{\text{Actual Total Project Cost}}$
Metric: ***Phase Cost Growth***	**Formula:** $\dfrac{\text{Actual Phase Cost – Initial Predicted Phase Cost}}{\text{Initial Predicted Phase Cost}}$

Definition of Terms

Actual Total Project Cost:

- Owners –
  - All actual project cost from front end planning through startup
  - Exclude land costs but include in-house salaries, overhead, travel, etc.
- Contractors – Total cost of the final scope of work.

Initial Predicted Project Cost:

- Owners – Budget at the time of Project Sanction.
- Contractors – Cost estimate used as the basis of contract award.

Actual Phase Cost:

- All costs associated with the project phase in question.
- See the Project Phase Table for phase definitions.

Initial Predicted Phase Cost:

- Owners – Budget at the time of Project Sanction.
- Contractors – Budget at the time of contract award.
- See the Project Phase Table for phase definitions.

Approved Changes:

- Estimated cost of owner-authorized changes.

Performance Metric Category: SCHEDULE

Metric: ***Project Schedule Growth***	**Formula:** $\frac{\text{Actual Total Proj. Duration - Initial Predicted Proj. Duration}}{\text{Initial Predicted Proj. Duration}}$
Metric: ***Delta Schedule Growth***	**Formula:** **| Schedule Growth |**
Metric: ***Project Schedule Factor***	**Formula:** $\frac{\text{Actual Total Project Duration}}{\text{Initial Predicted Project Duration + Approved Changes}}$
Metric: ***Delta Schedule Factor***	**Formula:** **| 1- Schedule Factor |**
Metric: ***Phase Duration Factor***	**Formula:** $\frac{\text{Actual Phase Duration}}{\text{Actual Overall Project Duration}}$
Metric: ***Total Project Duration***	Actual Total Project Duration (weeks)
Metric: ***Phase Schedule Growth***	**Formula:** $\frac{\text{Actual Phase Duration – Initial Predicted Phase Duration}}{\text{Initial Predicted Phase Duration}}$

Definition of Terms

Actual Total Project Duration:
(Detailed Engineering through Start-up)
- Owners – Duration from beginning of detailed engineering to turnover to user.
- Contractors - Total duration for the final scope of work from mobilization to completion.

Actual Overall Project Duration:
(Front End Planning through Start-up)
- Unlike Actual Total Duration, Actual Overall Duration also includes time consumed for the Front End Planning Phase.

Actual Phase Duration:
- Actual total duration of the project phase in question. See the Project Phase Table for phase definitions.

Initial Predicted Project Duration:
- Owners – Predicted duration at the time of Project Sanction.
- Contractors - The contractor's duration estimate at the time of contract award.

Approved Changes
- Estimated duration of owner-authorized changes.

Performance Metric Category: SAFETY

Metric: ***Lost Time Frequency (LTF)***	**Formula:** $$\frac{\text{Total Number of Lost Time cases x 200,000}}{\text{Total Site Work Hours}}$$
Metric: ***Medical Aid Frequency (MAF)***	**Formula:** $$\frac{\text{Total Number of Medical Aid Cases x 200,000}}{\text{Total Site Work Hours}}$$
Metric: ***First Aid Frequency (FAF)***	**Formula:** $$\frac{\text{Total Number of First Aid Cases x 200,000}}{\text{Total Site Work Hours}}$$
Metric: ***Total Recordable Injury Frequency (TRIF)***	**Formula:** $$\frac{\text{Total Number of Recordable Cases x 200,000}}{\text{Total Site Work Hours}}$$
Metric: ***Total Injury Frequency (TIF)***	**Formula:** $$\frac{\text{Total number of all injury or illness cases x 200,000}}{\text{Total Site Work Hours}}$$
Metric: ***Restricted Work Frequency (RWF)***	**Formula:** $$\frac{\text{Total Number of Restricted Work Cases x 200,000}}{\text{Total Site Work Hours}}$$
Metric: ***Lost Time Severity Rate (LTSR)***	**Formula:** $$\frac{\text{Total Number of Lost Time Workdays x 200,000}}{\text{Total Site Work Hours}}$$
Metric: ***Total Severity Rate (TSR)***	**Formula:** $$\frac{\text{Total Number of Recordable Lost Time Cases and all Restricted Work Cases x 200,000}}{\text{Total Site Work Hours}}$$

Definition of Terms

- **Lost Time Days**: Equals the number of scheduled work days away from work as a result of an occupational injury or illness, disabling injury or illness which prevents a worker from reporting to work on next regularly scheduled.
- **Medical Aid Case**: Any occupational injury or illness requiring medical treatment administered by a physician, not including first aid treatment
- **First Aid Case**: Any one time treatment which does not require medical care or further medical aid e.g. minor scratches, cuts, burns, splinters.
- **Recordable Case**: A work event or exposure that is the discernable cause of an injury or illness or of a significant aggravation to a pre-existing condition. A recordable case requires medical aid, restricted work in relation to either medical aid or lost time, or fatality.
- **Total number of all injury or illness cases**: Equals the number of lost time (LT) cases, medical aid (MA) cases, first aid (FA) cases and the number of restricted work cases for lost time (RWLT), medical aid (RWMA) and first aid (RWFA).
- **Total Number of Restricted Work Cases**: Equals the number of restricted work lost time cases, restricted work medical aid cases and restricted work first aid cases.
- **Lost Time Case**: Lost Time cases are the result of an occupational injury or illness including any disabling injury which prevents a worker from reporting to work on his/her next regularly scheduled.
- **Restricted Work Case**: Includes restricted work lost time cases, restricted work medical aid cases and restricted work first aid cases.
- **Restricted Work Days**: Equals the number of scheduled work days that the worker was unable to work their regular duties as a result of an injury or illness as defined in restricted work.
- **Total Number of Recordable Lost Time Cases and all Restricted Work Cases**: Includes the number of lost workdays plus the number of restricted work days for all lost time, medical aid and first aids.

Performance Metric Category: CHANGES

<table>
<tr><td>Metric: Scope Change Cost Factor</td><td>Formula:
$\dfrac{\text{Total Cost of Scope Changes}}{\text{Actual Total Project Cost}}$</td></tr>
<tr><td>Metric: Project Development Change Cost Factor</td><td>Formula:
$\dfrac{\text{Total Cost of Project Development Changes}}{\text{Actual Total Project Cost}}$</td></tr>
<tr><td colspan="2">Definition of Terms</td></tr>
<tr><td><u>Total Cost of Scope Changes</u>: Total cost impact of scope and project development changes.
<u>Total Cost of Project Development Changes</u>: Total cost impact of project development changes.</td><td><u>Actual Total Project Cost</u>:
Owners –
All actual project cost from front end planning through startup
Exclude land costs but include in-house salaries, overhead, travel, etc.
Contractors – Total cost of the final scope of work.</td></tr>
</table>

Performance Metric Category: REWORK

<table>
<tr><td>Metric: Total Field Rework Factor</td><td>Formula:
$\dfrac{\text{Total Direct Cost of Field Rework}}{\text{Actual Construction Phase Cost}}$</td></tr>
<tr><td colspan="2">Definition of Terms</td></tr>
<tr><td><u>Total Direct Cost of Field Rework</u>: Total direct cost of field rework regardless of initiating cause.</td><td><u>Actual Construction Phase Cost</u>: All costs associated with the construction phase. See the Project Phase Table for construction phase definition.</td></tr>
</table>

Construction Productivity (Park, 2002) and Total Installed Unit Cost (TIUC) Metrics Categories and Breakouts

Concrete
- **Total Concrete**
  - **Slabs** (CM)
    - On-Grade (CM)
    - Elevated Slabs/On Deck (CM)
    - Area Paving (CM)
  - **Foundations** (CM)
    - < 4 CM
    - 4 – 15 CM
    - 15 –38 CM
    - ≥ 38 CM
  - **Concrete Structures** (CM)

Structural Steel
- **Total Steel** (MT)
  - Structural Steel (MT)
  - Pipe Racks & Utility Bridges (MT)
  - Miscellaneous Steel (MT)

Instrumentation
- **Loops** (Count)
- **Devices** (Count)

Piping
- **Small Bore (2-1/2" & Smaller)** (LM)
  - Carbon Steel (LM)
  - Stainless Steel (LM)
  - Chrome (LM)
  - Other Alloys (LM)
  - Non Metallic (LM)
- **Inside Battery Limits (ISBL)** (LM)
  Large Bore (3" & Larger) (LM)
  - Carbon Steel (LM)
  - Stainless Steel (LM)
  - Chrome (LM)
  - Other Alloys (LM)
  - Non Metallic (LM)
- **Outside Battery Limits (OSBL)** (LM)
  Large Bore (3" & Larger) (LM)
  - Carbon Steel (LM)
  - Stainless Steel (LM)
  - Chrome (LM)
  - Other Alloys (LM)
  - Non Metallic (LM)
- **Heat Tracing Tubing (LM)**

Electrical
- **Total Electrical Equipment** (Each)
  - Panels and Small Devices (Each)
  - Electrical Equipment below 1kV (Each)
  - Electrical Equipment over 1kV (Each)
- **Conduit** (LM)
  - Exposed or Above Ground Conduit (LM)
  - Underground, Duct Bank or Embedded Conduit (LM)
- **Cable Tray** (LM)
- **Wire and Cable** (LM)
  - Control Cable (LM)
  - Power and Control Cable below 1kV (LM)
  - Power Cable above 1kV (LM)
- **Transmission Line** (LM)
  - High Voltage above 25kV (LM)
- **Other Electrical Metrics**
  - Lighting (Each)
  - Grounding (LM)
  - Electrical Heat Tracing (LM)

Equipment
- **Pressure Vessels (Field Fab.& Erected)** (Each), (MT)
- **Atmospheric Tanks (Shop Fabricated)** (Each), (MT)
- **Atmospheric Tanks (Field Fabricated)** (Each), (MT)
- **Heat Transfer Equipment** (Each), (MT)
- **Boiler & Fired Heaters** (Each), (MT)
- **Rotating Equipment** (Each), (HP)
- **Material Handling Equipment** (Each), (MT)
- **Power Generation Equipment** (Each), (kW)
- **Other Process Equipment** (Each), (MT)
- **Modules & Pre-assembled Skids** (Each), (MT)

Insulation
- **Equipment:**
  - Insulation Equipment (SM)
- **Piping**
  - Insulation Piping (ELM)

Module Installation
- **Pipe Racks** (MT)
- **Process Equipment Modules** (MT)
- **Building** (SM)

Scaffolding
- **Scaffolding Work Hours**
  - Percentage estimated WH/ total direct hours
  - Percentage Actual WH/ total direct hours

$$\text{Construction Productivity Unit Rate} = \frac{\text{Direct Work Hours}}{\text{Installed Quantity}}$$

$$\text{Estimating Accuracy of Productivity Rate} = \frac{\text{Actual Productivity Rate}}{\text{Estimated Productivity Rate}}$$

$$\text{Estimating Accuracy of Total Unit Cost} = \frac{\text{Actual TIUC}}{\text{Estimated TIUC}}$$

Engineering Productivity Metrics Categories and Breakouts (Kim, 2007)

<u>**Concrete**</u>
- **Total Concrete (CM)**
  o Total Slabs (CM)
    • Ground and Supported Slab (CM)
    • Area Paving (CM)
  o Total Foundations (except Piling) (CM)
    • Foundation (<4CM) (CM)
    • Foundation (≥4CM) (CM)
  o Concrete Structures (CM)
  o Total Piling (Each)
 	
<u>**Structural Steel**</u>
- **Total Steel (MT)**
  o Combined Structural Steel / Pipe Racks & Utility Bridges (MT)
    • Structural Steel (MT)
    • Pipe Racks & Utility Bridges (MT)
  o Miscellaneous Steel (MT)
 	
<u>**Electrical**</u>
- **Total Electrical Equipment** (Each)
  o Electrical Equipment 1kV & Below (Each)
  o Electrical Equipment Over 1kV (Each)
- **Conduit**
  o Conduit (LM)
  o Conduit (Number of Runs)
- **Cable Tray** (LM)
- **Wire & Cable**
  o Wire & Cable (LM)
  o Wire & Cable (Number of Terminations)
- **Other Electric Metric**
  o Lighting (Each Fixtures)
  o Electrical Heat Tracing (LM)
	<u>**Piping**</u>
	- **Total Piping (LM)**
	  o Small Bore (2-1/2" and Smaller) (LM)
	  o Large Bore (3" and Larger) (LM)
	  o Engineered Hangers and Supports (Each)
	- **Heat Tracing Tubing (LM)**
	
	<u>**Instrumentation**</u>
	- **Loops** (Count)
	- **Tagged Devices** (Each)
	- **I/O** (Count)
	
	<u>**Equipment**</u>
	(Individual Design and Total Quantity)
	- **Total Equipment (Each)**
	  o Pressure Vessels (Each)
	  o Atmospheric Tanks (Each)
	  o Heat Transfer Equipment (Each)
	  o Boiler & Fired Heaters (Each)
	  o Rotating Equipment (Each)
	  o Material Handling Equipment (Each)
	  o Power Generation Equipment (Each)
	  o Other Process Equipment (Each)
	  o Vendor-Designed Modules & Pre- Assembled Skids (Each)

$$\textbf{Engineering Productivity} = \frac{\textbf{Direct Design-Hours*}}{\textbf{IFC Quantity**}}$$

* Per Design Component
** IFC (Issued for Construction)

Project Phase Definition Table

Project Phase	Start/Stop	Typical Activities & Products	Typical Cost Elements
Front End Planning Typical Participants: • Owner Personnel • Planning Consultants • Constructability Consultant • Alliance / Partner	**Start: Single project adopted and Formal project team established** **Stop: Project Sanction**	• Options Analysis • Life-cycle Cost Analysis • Project Execution Plan • Appropriation Submittal Pkg • P&IDs and Site Layout • Project Scoping • Procurement Plan • Arch. Rendering	• Owner Planning Team Personnel Expenses • Consultant Fees & Expenses • Environmental Permitting Costs ▪ Project Manager / Construction Manager Fees • Licensor Costs
Detail Engineering Typical Participants: • Owner Personnel • Design Contractor • Constructability Expert • Alliance / Partner	**Start: Contract award to engineering firm** **Stop: Release of all approved drawings and specs for Construction (or last package for fast-track)**	• Drawing & spec. preparation • Bill of material preparation • Procurement Status • Sequence of operations • Technical Review • Definitive Cost Estimate	• Owner Project Management Personnel • Designer Fees • Project Manager / Construction Manager Fees
Procurement Typical Participants: • Owner personnel • Design Contractor • Alliance / Partner	**Start: Procurement plan for engineered equipment** **Stop: All major equipment has been delivered to site**	• Vendor Qualification • Vendor Inquiries • Bid Analysis • Purchasing • Expediting • Engineered Equipment • Transportation • Vendor QA/QC	• Owner project management personnel • Project Manager / Construction Manager fees • Procurement & Expediting personnel • Engineered Equipment • Transportation • Shop QA / QC

Note: The demolition / abatement phase should be reported when the demolition / abatement work is a separate schedule activity (potentially paralleling the design and procurement phases) in preparation for new construction. Do not report the demolition / abatement phase if the work is integral with modernization or addition activities.

Project Phase Table (Cont.)

Project Phase	**Start/Stop**	Typical Activities & Products	Typical Cost Elements
Construction Typical Participants: • Owner personnel • Design Contractor (Inspection) • Construction Contractor and its subcontractors	**Start: Commencement of foundations or driving Piles** **Stop: *Mechanical Completion***	• Set up trailers • Procurement of bulks • Issue Subcontracts • Construction plan for Methods/Sequencing • Build Facility & Install Engineered Equipment • Complete Punchlist • Demobilize construction equipment • Warehousing	• Owner project management personnel • Project Manager / Construction Manager fees • Building permits • Inspection QA/QC • Construction labor, equipment & supplies • Bulk materials (including freight) • Construction equipment (including freight) • Contractor management personnel • Warranties
Start-up / Commissioning Note: Does not usually apply to infrastructure or building type projects Typical Participants: • Owner personnel • Design Contractor • Construction Contractor • Training Consultant • Equipment Vendors	**Start: *Mechanical Completion*** **Stop: Custody transfer to user/operator (steady state operation)**	• Testing Systems • Training Operators • Documenting Results • Introduce Feedstocks and obtain first Product • Hand-off to user/operator • Operating System • Functional Facility • Warranty Work	• Owner project management personnel • Project Manager / Construction Manager fees • Consultant fees & expenses • Operator training expenses • Wasted feedstocks • Vendor fees

Appendix C: Project Performance Benchmarking Report

Owner Project Key Report

Testcompany

COMPANY CONFIDENTIAL

Project Key Report (Rev.5: Feb 25, 08)

Benchmarking & Metrics

SAMPLE COAA

Project General Information

Company Name		Testco	Project Nature		Grass Root
Project I.D.		AO1001	Project Driver		Schedule
Project Name		Test1	Project Complexity (1to 10)		8
Actual Cost	Total Installed Cost	$575,000,000	Project Category	Industry Group	Heavy Industrial
	Construction Cost	$488,000,000		Project Type	Oil Sand Upgrading
	Currency	$CAD		Cost Category	> $500MM
Project Duration	Overall Project	260 Weeks	Project Completion Date		1 Nov. 06
	Detailed Eng. through Startup	210 Weeks			
	Total Const. Work-Hours	2,600,000	Unit of Quantity		Metric
Project Location	City	Ft. McMurray			
	Province	Alberta			
	Country	Canada			

Notes:

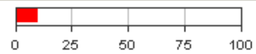
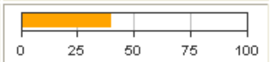
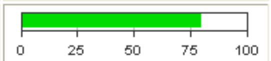
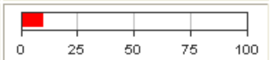
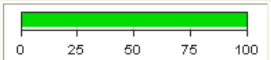
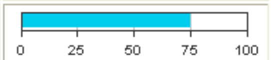
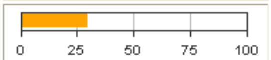
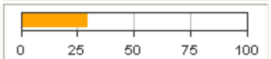
- **Overall Project Duration** consider as start of Front End Planning to project turn over to user.
- The historical cost index adjustment is the index at year of midpoint of construction/ the index at the present time.
- For **Project Complexity**, The higher value indicates the higher level of complexity of the project.

Explanation of Notations

- Asterisk (*) on the n value denotes a small sample of projects (10≤n<20)
- For performance & practice use metrics, the percentile bar indicates the percent of the projects for which you scored equal to or better than within the comparison data.
- For phase cost & duration factors, the percentile bar indicates the percent of the projects with equal to or higher metric values. (For these metrics, low scores are not necessary better.)
- Quartiles are indicated on the left of the percentile score bar; Uo indicates an Upper Outlier, Lo indicates a Lower Outlier.
- For percent design complete metrics, the percentile bar indicates the percent of the projects with equal to or lower metric values.
- For PDRI, lower numbers are better and its minimum and maximum scores are 0 and 1000, respectively.
- The Appendix page contains summary information indicating the exact slice of data used for comparison in each metric.

Example of Project Cost Metrics

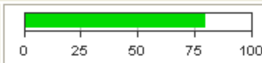
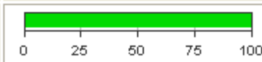
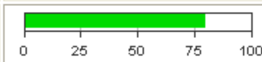
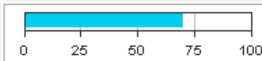
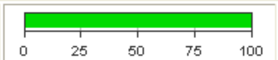
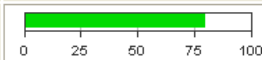
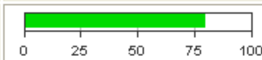
Project Performance Metric *NORMS*

Cost Performance					
Metric	Project Score	Database		Percent Spending More Money	n
		Mean	Median		
Phase Cost Factor					
Actual Front End Planning Cost / TIC	0.005	0.019	0.019		S
Actual Detailed Engr. Cost / TIC	0.092	0.098	0.100		S
Actual Procurement Cost / TIC	0.357	0.293	0.300		S
Actual Total Const. Cost / TIC	0.360	0.548	0.545		S
Project Level					
Total Contingency / TIC	0.091	0.065	0.064		S
Total Owner CM cost / TIC	0.050	0.030	0.016		S
Total Major Equipment / TIC	0.055	0.147	0.111		S
Total Mechanical and Process Equipment Cost / TIC	0.045	0.073	0.083		S

Appendix

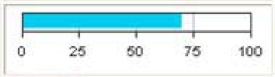
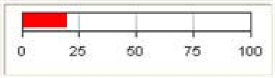
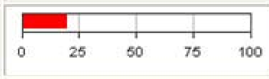
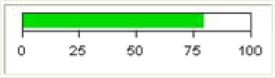
Cost Performance Metrics	Respondent Type	Level 1	Level 2	Proj. Nature	Cost Cat.
Actual Front End Planning Cost / TIC	Owner	Upstream	All	All	All
Actual Detailed Engr. Cost / TIC	Owner	Upstream	All	All	All
Actual Procurement Cost / TIC	Owner	Upstream	All	All	All
Actual Total Const. Cost / TIC	Owner	Upstream	All	All	All
Total Contingency / TIC	Owner	Upstream	Oil Sands SAGD	All	All
Total Owner CM cost / TIC	Owner	Upstream	All	All	All
Total Major Equipment / TIC	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Total Mechanical and Process Equipment Cost / TIC	Owner	Upstream	Oil Sands SAGD	Grass Roots	All

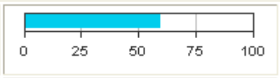
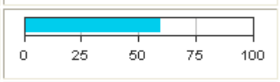
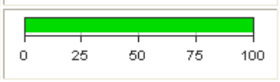
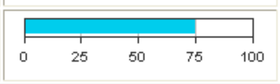
Example of Project Cost Metrics (Continued)

Cost Performance				
Metric	Project Score	Database Mean	4Q 3Q 2Q 1Q	n
Project Level				
Project Cost Growth	-0.017	0.308		S
Delta Cost Growth	0.017	0.325		S
Project Budget Factor	0.960	1.172		S
Delta Budget Factor	0.040	0.196		S
Phase Level				
Detailed Engineering Cost Growth	-0.190	0.229		S
Total Construction Cost Growth	0.059	0.296		S
Construction Direct Cost Growth	0.000	0.278		S
Construction Indirect Cost Growth	0.263	0.312		S

Appendix					
Project Cost Growth	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Delta Cost Growth	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Project Budget Factor	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Delta Budget Factor	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Detailed Engineering Cost Growth	Owner	Upstream	All	All	All
Total Construction Cost Growth	Owner	Upstream	All	All	All
Construction Direct Cost Growth	Owner	Upstream	All	All	All
Construction Indirect Cost Growth	Owner	Upstream	All	All	All

Example of Project Schedule Metrics

Schedule Performance					
Metric	Project Score	Database		Percent Spending More Time	n
		Mean	Median		
Phase Level					
Front End Planning Duration Factor	0.230	0.251	0.254		S
Detailed Engr. Duration Factor	0.703	0.597	0.596		S
Procurement Duration Factor	0.439	0.540	0.527		S
Construction Duration Factor	0.431	0.583	0.542		S
Startup Duration Factor	0.121	0.077	0.071		S

Schedule Performance (Cont'd)				
Metric	Project Score	Database Mean	4Q 3Q 2Q 1Q	n
Project Level				
Project Schedule Growth	0.088	0.159		S
Delta Schedule Growth	0.088	0.170		S
Project Schedule Factor (for contractor)	0.961	1.141		S
Delta Schedule factor (for contractor)	0.039	0.160		S

Appendix					
Schedule Performance Metrics	Respondent Type	Level 1	Level 2	Proj. Nature	Cost Cat.
Front End Planning Duration Factor	Owner	Upstream	Oil Sands SAGD	All	All
Detailed Engr. Duration Factor	Owner	Upstream	Oil Sands SAGD	All	All
Procurement Duration Factor	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Construction Duration Factor	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Startup Duration Factor	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Delta Schedule Growth	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Project Schedule Growth	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Delta Schedule Factor	Owner	Upstream	Oil Sands SAGD	Grass Roots	All

Example of Change, Rework, and Safety Metrics

Change Performance				
Metric	Project Score	Database Mean	4Q 3Q 2Q 1Q	n
Scope Change Cost Factor	0.011	0.011	0 25 50 75 100	S
Development Change Cost Factor	0.014	0.033	0 25 50 75 100	S

Rework Performance				
Metric	Project Score	Database Mean	4Q 3Q 2Q 1Q	n
Total Field Rework Factor	0.171	0.027	Lo 0 25 50 75 100	S

Safety Performance				
Metric	Project Score	Database Mean	4Q 3Q 2Q 1Q	n
Lost Time Frequency (LTF)	0.20	0.560	0 25 50 75 100	S
Medical Aid Frequency (MAF)	1.31	2.188	0 25 50 75 100	S
First Aid Frequency (FAF)	22.42	34.065	0 25 50 75 100	S
Total Injury Frequency (TIF)	24.18	62.998	0 25 50 75 100	S

Construction Work-hours					
Metric	Project Score	Database		Percent Spending More Time	n
		Mean	Median		
Const. Indir. WH / Total Const. Dir. WH	0.27	0.280	0.233	0 25 50 75 100	S

Appendix

Change/Rework/Safety/Other Performance Metrics	Respondent Type	Level 1	Level 2	Proj. Nature	Cost Cat.
Scope Change Cost Factor	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Development Change Cost Factor	Owner	Upstream	All	All	All
Total Field Rework Factor	Owner	All	All	All	All
Lost Time Frequency (LTF)	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Medical Aid Frequency (MAF)	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
First Aid Frequency (FAF)	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Total Injury Frequency (TIF)	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Restricted Work Frequency (RWF)	Owner	Upstream	Oil Sands SAGD	All	All
Lost Time Severity Rate (LTSR)	Owner	All	All	All	All
Const. Indir. WH / Total Const. Dir. WH	Owner	Upstream	Oil Sands SAGD	Grass Roots	All

Example of Engineering Productivity Metrics

Engineering Productivity

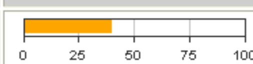
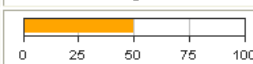
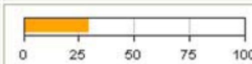
General Information

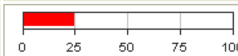
Detailed Engineering Cost (SCAD)	**12,365,298**
Detailed Engineering Phase Duration (weeks)	**247.43**
Detailed Engineering Budget / TIC	**0.09**

Notes:

- For productivity metrics, the percentile bar indicates the percent of the projects for which you scored equal to or better than within the comparison data.
- Quartiles are indicated on the left of the percentile score bar; Uo indicates an Upper Outlier, Lo indicates a Lower Outlier.
- Asterisk (*) on the n value denotes a small sample of projects (10≤n<20)
- Tilde (~) on the raw productivity denotes a outlier which is removed from calculation of norms.
- **N/A -** Data not available to calculate metric.
- **C -** Data suppressed based on confidentiality rules.
- **DS -** Data suppressed. Metric reported only to those providing data.

Engineering Productivity Metrics- Concrete

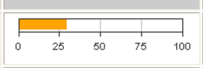
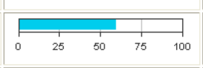
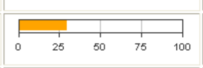
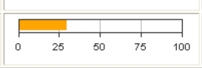
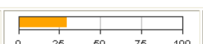
Concrete						
Slabs						
Metric	**Design Hours**	**IFC Quantity (CM)**	**Unit Rate (Design Hours/ CM)**	**Weighted Database Mean**	4Q 3Q 2Q 1Q	**n**
Ground & Supported Slabs	5,015	1,400.0	3.58	1.492		S
Area Paving	885	240.0	3.69	C	C	C
Total Slabs Productivity Rate	**5,900**	**1,640.0**	**3.60**	3.378		S
Foundations						
Metric	**Design Hours**	**IFC Quantity (CM)**	**Unit Rate (Design Hours/ CM)**	**Weighted Database Mean**	4Q 3Q 2Q 1Q	**n**
<4 (CM)	8,000	1,200.0	6.67	C	C	C
≥4 (CM)	13,300	4,713.0	2.82	C	C	C
Total Foundations Productivity Rate (except Piling)	**21,300**	**5,913.0**	**3.60**	2.966		S
Metric	**Design Hours**	**IFC Quantity (each)**	**Unit Rate (Design Hours/ Each)**	**Weighted Database Mean**	4Q 3Q 2Q 1Q	**n**
Total Piling Productivity Rate	**0**	**5,256.0**	**N/A**	C	C	C

Concrete Structures						
Metric	Design Hours	IFC Quantity (CM)	Unit Rate (Design Hours/ CM)	Weighted Database Mean	4Q 3Q 2Q 1Q	n
Total Concrete Structures Productivity Rate	**0**	**0.0**	N/A	1.875	N/A	S
Total Concrete						
Metric	Design Hours	IFC Quantity (CM)	Unit Rate (Design Hours/ CM)	Weighted Database Mean	4Q 3Q 2Q 1Q	n
Total Concrete Productivity Rate	**27,200**	**7,553.0**	3.60	2.529		S

Appendix

Concrete					
Slabs	**Respondent Type**	**Level 1**	**Level 2**	**Proj. Nature**	**Cost Cat.**
Ground & Supported Slabs (CM)	All	All	All	All	All
Area Paving (CM)	N/A	N/A	N/A	N/A	N/A
Total Slabs Productivity Rate (CM)	All	Upstream	All	All	All
Foundation	**Respondent Type**	**Level 1**	**Level 2**	**Proj. Nature**	**Cost Cat.**
<4 (CM)	N/A	N/A	N/A	N/A	N/A
=4 (CM)	N/A	N/A	N/A	N/A	N/A
Total Foundations Productivity Rate (except Piling) (WH/CM)	Owner	All	All	All	All
Total Piling Productivity Rate (WH/each)	N/A	N/A	N/A	N/A	N/A
Total Concrete Structures Productivity Rate (WH/CM)	All	All	All	All	All
Total Concrete Productivity Rate (WH/CM)	Owner	Upstream	All	All	All

Engineering Productivity Metrics- Structural Steel

Structural Steel						
Metric	Design Hours	IFC Quantity (MT)	Unit Rate (Design Hours/ MT)	Weighted Database Mean	4Q 3Q 2Q 1Q	n
Structural Steel	9,500	682.2	13.93	13.970		S
Pipe Racks & Utility Bridge	4,600	258.5	17.79	15.640		S
Combined Structural Steel and Pipe Racks & Utility Bridge	14,100	940.8	14.99	13.786		S
Miscellaneous Steel	2,500	98.0	25.52	16.342		S
Total Structural Steel						
Total Structural Steel Productivity Rate	**16,600**	**1,038.7**	**15.98**	14.146		S

Appendix

Structural Steel	**Respondent Type**	**Level 1**	**Level 2**	**Proj. Nature**	**Cost Cat.**
Structural Steel (MT)	Owner	Upstream	Oil Sands SAGD	All	All
Pipe Racks & Utility Bridge (MT)	Owner	All	All	All	All
Combined Structural Steel and Pipe Racks & Utility Bridge (MT)	Owner	Upstream	All	All	All
Miscellaneous Steel (MT)	Owner	Upstream	All	All	All
Total Structural Steel Productivity Rate (WH/MT)	Owner	Upstream	Oil Sands SAGD	All	All

Example of Construction Productivity Metrics

Construction Productivity

General Information

Actual Total Construction Phase Cost ($CAD)	48,560,334	**Actual Predominant Work Schedule (days)**	5-2
Actual Construction Phase Duration	151.57	**Actual Predominant Mode of Travel to Worksite**	Vehicle
Actual Total Construction Work-hours	1,193,777	**Percent Construction During Unscheduled Turnaround**	0
Percent Construction During Scheduled Turnaround	12		

Notes:

- For productivity metrics, the percentile bar indicates the percent of the projects for which you scored equal to or better than within the comparison data.
- Quartiles are indicated on the left of the percentile score bar; Uo indicates an Upper Outlier, Lo indicates a Lower Outlier.
- Asterisk (*) on the n value denotes a small sample of projects (10≤n<20)
- Tilde (~) on the raw productivity denotes a outlier which is removed from calculation of norms.
- **N/A** - Data not available to calculate metric.
- **C** - Data suppressed based on confidentiality rules.
- **TIUC** is estimated of the burdened cost including labor, material and equipment from both direct hire and subcontract.

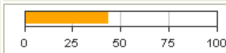
Construction Productivity Metrics- Concrete

Concrete						
Metric	**Wk-Hrs**	**Installed Quantity (CM)**	**Unit Rate (Wk-Hrs/CM)**	**Weighted Database Mean**	**4Q 3Q 2Q 1Q**	**n**
Slabs						
On-Grade	N/A	N/A	N/A	C	C	C
Elevated Slabs/ On Deck	N/A	N/A	N/A	C	C	C
Area Paving	N/A	N/A	N/A	C	C	C
Total Slabs Productivity	**0**	**0.0**	N/A	C	C	C
Total Installed Unit Cost	**Actual ($/CM)**	**Estimate ($/CM)**	**Actual DB Mean ($/CM)**		**4Q 3Q 2Q 1Q**	**n**
	N/A	N/A	C		C	C
Foundations						
Metric	**Wk-Hrs**	**Installed Quantity (CM)**	**Unit Rate (Wk-Hrs/CM)**	**Weighted Database Mean**	**4Q 3Q 2Q 1Q**	**n**
< 4 (CM)	N/A	N/A	N/A	C	C	C
4-15 (CM)	N/A	N/A	N/A	C	C	C
16-38 (CM)	N/A	N/A	N/A	C	C	C
≥ 38 (CM)	N/A	N/A	N/A	C	C	C
Total Foundations Productivity	**0**	**7,553.0**	N/A	C	C	C
Total Installed Unit Cost	**Actual ($/CM)**	**Estimate ($/CM)**	**Actual DB Mean ($/CM)**		**4Q 3Q 2Q 1Q**	**n**
	N/A	N/A	C		C	C

Concrete Structures

Metric	Wk-Hrs	Installed Quantity (CM)	Unit Rate (Wk-Hrs/CM)	Weighted Database Mean	4Q 3Q 2Q 1Q	n
Concrete Structures	N/A	N/A	N/A	C	C	C
Total Installed Unit Cost	Actual ($/CM)	Estimate ($/CM)	Actual DB Mean ($/CM)		4Q 3Q 2Q 1Q	n
	N/A	N/A	C		C	C

Total Concrete

Metric	Wk-Hrs	Installed Quantity (CM)	Unit Rate (Wk-Hrs/CM)	Weighted Database Mean	4Q 3Q 2Q 1Q	n
Total Concrete Productivity	0	0.0	N/A		N/A	S
Estimated Total Concrete Productivity Unit Rates	Est. Wk-Hrs	Est. Quantity (CM)	Est. Unit Rate (Wk-Hrs/ CM)	12.259	4Q 3Q 2Q 1Q	n
	152,847	7,553.0	20.24			S
Total Installed Unit Cost	Actual ($/CM)	Estimate ($/CM)	Actual DB Mean ($/CM)		4Q 3Q 2Q 1Q	n
	N/A	109.2	C		C	C

Appendix

Concrete

Slabs	Respondent Type	Level 1	Level 2	Proj. Nature	Cost Cat.
On-Grade (CM)	N/A	N/A	N/A	N/A	N/A
Elevated Slabs/ On Deck (CM)	N/A	N/A	N/A	N/A	N/A
Area Paving (CM)	N/A	N/A	N/A	N/A	N/A
Total Slabs Productivity (WH/CM)	N/A	N/A	N/A	N/A	N/A
Foundations	**Respondent Type**	**Level 1**	**Level 2**	**Proj. Nature**	**Cost Cat.**
< 4 (CM)	N/A	N/A	N/A	N/A	N/A
4-15 (CM)	N/A	N/A	N/A	N/A	N/A
16-38 (CM)	N/A	N/A	N/A	N/A	N/A
= 38 (CM)	N/A	N/A	N/A	N/A	N/A
Total Foundations Productivity (Wk-Hrs/ CM)	N/A	N/A	N/A	N/A	N/A
Concrete Structures	**Respondent Type**	**Level 1**	**Level 2**	**Proj. Nature**	**Cost Cat.**
Concrete Structures (CM)	N/A	N/A	N/A	N/A	N/A
Total Concrete	**Respondent Type**	**Level 1**	**Level 2**	**Proj. Nature**	**Cost Cat.**
Total Concrete Productivity (Wk-Hrs/ CM)	Owner	Upstream	All	All	All

Example of Construction Productivity Metrics- Structural Steel

Structural Steel						
Metric	**Wk-Hrs**	**Installed Quantity (MT)**	**Unit Rate (Wk-Hrs/MT)**	**Weighted Database Mean**	**4Q 3Q 2Q 1Q**	**n**
Structural Steel	62,067	744.8	83.33	49.961	0 25 50 75 100	S
Pipe Racks & Utility Bridge	20,765	261.3	79.48	33.628	0 25 50 75 100	S
Miscellaneous Steel	13,230	114.3	115.74	116.256	0 25 50 75 100	S
Total Structural Steel Productivity	**96,062**	**1,120.4**	**85.74**		0 25 50 75 100	S
Estimated Total Structural Steel Productivity Rates	**Est. Wk-Hrs**	**Est. Quantity (MT)**	**Est. Unit Rate (Wk-Hrs/MT)**	28.267	**4Q 3Q 2Q 1Q**	**n**
	79,684	**1,038.7**	**76.71**		0 25 50 75 100	S
Total Installed Unit Cost	**Actual ($/MT)**	**Estimated ($/MT)**	**Actual DB Mean ($/MT)**		**4Q 3Q 2Q 1Q**	**n**
	9,628.5	**9,265.4**	**C**		**C**	**C**

Appendix

Structural Steel	**Respondent Type**	**Level 1**	**Level 2**	**Proj. Nature**	**Cost Cat.**
Structural Steel (MT)	Owner	All	All	All	All
Pipe Racks & Utility Bridge (MT)	All	All	All	All	All
Miscellaneous Steel (MT)	Owner	All	All	All	All
Total Structural Steel Productivity Rate (Wk-Hrs/MT)	Owner	Upstream	Oil Sands SAGD	All	All
Total Estimated Structural Steel Productivity Rate (Wk-Hrs/MT)	Owner	Upstream	Oil Sands SAGD	All	All

Example of Construction Productivity Metrics- Scaffolding

Scaffolding					
Metric	**Project Score**		**Weighted Database Mean**	**4Q 3Q 2Q 1Q**	**n**
	Actual	**Estimated**			
Scaffolding WH / Total Const. Dir. WH	0.127	N/A	0.091	0 25 50 75 100	16

Appendix

Scaffolding WH / Total Const. Dir. WH	**Respondent Type**	**Level 1**	**Level 2**	**Proj. Nature**	**Cost Cat.**
Scaffolding WH / Total Const. Dir. WH	Owner	All	All	All	All

Practices Metrics

Practices				
Metric	**Project Score**	**Database Mean**	**4Q 3Q 2Q 1Q**	**n**
Front End Planning	1.350	6.745	0 25 50 75 100	S
Project Risk Assessment	10.000	7.813	0 25 50 75 100	S
Team Building	8.906	7.019	0 25 50 75 100	S
Alignment during Front End Planning	9.375	7.952	0 25 50 75 100	S
Design for Maintainability	8.929	7.206	0 25 50 75 100	S
Constructability	10.000	8.946	0 25 50 75 100	S
Materials Management	8.333	6.589	0 25 50 75 100	S
Project Change Management	8.958	7.696	0 25 50 75 100	S
Safety (Zero Accidents)	7.273	7.848	0 25 50 75 100	S
Quality Management	6.893	6.584	0 25 50 75 100	S
Automation/Integration (AI) Technology	9.615	5.683	0 25 50 75 100	S
Planning for Startup	9.731	7.885	0 25 50 75 100	S
Pre Fabrication, Pre Assembly, Modularization and Offsite Fab. (PP_MOF)	9.167	9.427	0 25 50 75 100	S
Workface Planning	N/A	6.865	N/A	S

Appendix

Practice Use Metrics	Respondent Type	Level 1	Level 2	Proj. Nature	Cost Cat.
Front End Planning	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Project Risk Assessment	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Team Building	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Alignment during Front End Planning	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Design for Maintainability	Owner	Upstream	Oil Sands SAGD	All	All
Constructability	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Materials Management	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Project Change Management	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Safety (Zero Accidents)	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Quality Management	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Automation/Integration (AI) Technology	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Planning for Startup	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Pre Fabrication, Pre Assembly,Modularization and Offsite Fab.	Owner	Upstream	Oil Sands SAGD	Grass Roots	All
Workface Planning	Owner	All	All	All	All

Appendix D: Statistical Analysis Methods

D.1 Statistical Application Methods

As mentioned in Section 3.3, various data analysis techniques were employed in this study. To investigate characteristics of projects, the data distributions were examined by using the box and whisker plots, along with associated test statistics such as *t*-test and Levene's test for mean comparison purpose. In addition, other statistical techniques include correlation, regression with associated test such as test of equality of regression coefficient, also Exploratory Factor Analysis (EFA) were used to establish the relationships between variables associated with their characteristics. These analysis techniques are introduced as follows.

Box and Whisker Plot

In descriptive statistics, a box and whisker plot (boxplot) is a convenient way of graphically depicting data characteristics such as central tendency, outliers, and distribution. As shown in Figure D.1, the box consists of the central portion of a diagram which indicates the degree of dispersion representing the middle 50% of data. This range is defined as the inter quartile range (IQR) which was drawn from the first to the third quartile (25%~75% percentile) of the data, while the horizontal line in the box represents the median of the data. Then, the horizontal lines (the whiskers) extend above and below the box by 1.5 times the box width (the inter quartile range) include another 50% of data outside of the box.

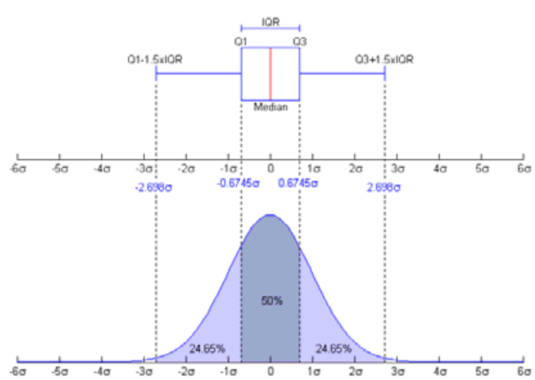


Figure D.1 Box and whisker plot and a probability density function (pdf)

The data fall beyond the whiskers or 1.5 IQR of the third quartile or below 1.5 IQR of the first quartile are considered as extreme values or outliers. For this research the boxplots were generated by using MINITAB® to present the data distribution, norms and detect extreme outliers. The criteria to determine the outliers for project cost, schedule, rework and change metrics is the values that fall beyond 1st quartile+ 1.5IQR or 3rd quartile – 1.5IQR as, while considering the data beyond 1st quartile+ 3IQR or 3rd quartile – 3IQR as the outliers for engineering and construction productivity rate.

T-Test

a) A Test of Mean Differences

A *t*-test is a common statistical hypothesis test to evaluate whether the means of two groups are statistically different from each other. In testing the null hypothesis that the population mean is equal to a specified value μ_0, one uses the statistic

$$t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}}$$

where s is the sample standard deviation of the sample and n is the sample size. The degrees of freedom used in this test is n − 1. In this study, if the calculated p-value is below 0.05, the threshold chosen for statistical significance, then the null hypothesis states that the two groups do not differ is rejected in favor of an alternative hypothesis, which typically states that the groups do differ.

Levene's Test for Equality of Variances

Levene's test (Levene, 1960) is a test which hypothesize that the variances in different groups are equal or the difference between the variance is zero. A significant result indicates that the variances are significantly different resulting in the violation of the assumption of homogeneity of variance. In this study, Levene's test was performed by using SPSS® at alpha level of 0.05.

Correlation

a) Pearson's Correlation (r)

Pearson's correlation is a standardized measure of the strength of relationship between two variables; however it does not prove causation. It can take any value from -1 (as one variable changes, the other changes in the opposite direction by the same amount), through 0 (as one variable changes the other doesn't change at all), to +1 (as one variable changes, the other changes in the same direction by the same amount) (Field, 2005). The correlation coefficient, r, is calculated as

$$r = \frac{\sum \left(x - \bar{x}\right)\left(y - \bar{y}\right)}{\left(n-1\right)S_x S_y}$$

where s is a standard deviation of x and y accordingly. The magnitude close to -1 and +1 indicates a strong negative and positive relationship occurred when the linear relationship is perfect. In this study, $r<0.3$ is defined as low correlation, r between 0.3 to 0.5 is as moderate, while $r>0.5$ is as high correlation. In this study, SPSS® provide the results of significance of correlation coefficient, r, analysis results between x and y using t distribution with degree of freedom (N-2):

$$t_{r_s} = \frac{(r_s - 0)}{\sqrt{(1 - r_s^2)/(n-2)}}$$

If p-value is less than 0.05, as a criterion in this study, the null hypothesis is rejected. Then, a significant result indicates that Pearson's correlation is statistically significant different from zero. A few assumptions of response variables' population governing this test are provided:

- Independent observations (X,Y)
- Linearity: The relationship between X and Y is linear.
- Bivariate normality: The population distributions of the X and Y are normal.
- Homoscadasticity of errors: The variability of X and Y are equally distributed.

b) Spearman's Rank Correlation

Spearman's rank correlation or Spearman's Rho is a standardized measure of the strength of relationship between two variables that does not rely on the assumptions of a parametric test. It is Pearson's correlation coefficient performed on data that have been converted into ranked scores. Spearman's Rho is calculated as

$$r_s = 1 - \left[\frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)} \right]$$

where d represents the difference between each pair of X and Y ranks and n is the sample size. Similar to Pearson's correlation, SPSS® provide the results of significance of Spearman's rank correlation analysis results between X and Y using t distribution with degree of freedom (N-2) as Pearson's correlation.

Simple and Multiple Linear Regression

a) Simple linear regression

is used to evaluate the linear relationship between two variables. The simple linear regression model is used to develop and equation to predict or estimate a dependent variable (DV) given an independent variable (IV). The model is shown as follow:

$$Yi' = \alpha + B Xi + e_n$$

where Yi is the dependent variable, α is the y intercept, B is the slope of the line, Xi is independent variable and e_n is a random term associated with each observation. B is the magnitude of IV change when DV changes by one unit. The linear relationship between IV and DV can be measured using a correlation coefficient e.g. the Pearson product moment correlation coefficient.

b) Multiple linear regression (MR)

is a powerful statistical techniques that allow one to assess the relationship between one DV and several IVs (Tabachnick& Fidell, 2001). It is an extension of bivariate regression in which several IVs are used simultaneously to predict the outcome for each IV on DV. One advantage of MR over methods such as ANOVA is that was can use either categorical IVs, or continuous variables, or both. While ANOVA is often more appropriate for experimental research in which IV can be manipulated, MR can be used for the analysis of non experimental research in which IV are not assigned or manipulated (Keith, 2006). This study is primary be interested in using MR for explanatory which can make casual inferences, rather than predictive purposes. MR is applied to examine the relative impact of each factor on construction productivity when considering the remaining factors. Basically, MR is considered when there is indication of correlation of other IVs to DV. Adding more explanatory variables in equation could help improving linear fit. The general form of MR is as follow:

$$\hat{Y} = \alpha + B_1X_1 + B_2X_2 + \ldots + B_mX_m$$

where $\hat{Y}$ is the predicted value on the DV, the X's represent the various IVs, the A is a constant which is Y intercept when all X values are zero, *B*'s are weights assigned to each of the IVs by the regression analysis or regression coefficients, and e_n indicates the model residual. *B* can be used to compare effect of each IV on DV across studies. The variation of DV through variation in each IV when controlling for other IVs can be explained. It is meaningful for interpretation when the variables have meaningful scale or IVs have the same scale. Another important statistic in MR is called the coefficient of multiple determination (R^2). R^2 depicts how much variance of DV is contributed from IV. R^2 is defined as:

$$R^2 = \frac{\sum\left(Y-\overline{Y}\right)^2 - \sum\left(Y-\hat{Y}\right)^2}{\sum\left(Y-\overline{Y}\right)^2}$$

The range of R^2 is from 0 to 1. The greater the R^2, the more the variance of DV explained by IV, meaning better fit. This study used SPSS® for MR analysis which provides the test statistics of R^2 to test whether at least one of the slopes (*B*) differs from zero. Another way to say is that to test whether at least one of the IVs is significantly related to DV. F-test is used with degree of freedom (N-k-1):

$$F = \frac{R^2/m}{\left(1-R^2\right)/\left[n-\left(m+1\right)\right]}$$

If p-value is less than 0.05, as a criterion in this study, the null hypothesis $H_0 = \beta_1 = \beta_2 = \ldots = \beta_m = 0$ is rejected. Then, a significant result indicates that at least one of the IVs is statistically greater than zero which means it has statistically significant relationship with DV. Similar to other parametric test statistics, assumptions for MR include Linearity, Independent of errors, and homoscadasticity.

Exploratory Factor Analysis (EFA)

Exploratory Factor Analysis (EFA) is a statistical technique to summarize data by grouping together variables that are intercorrelated. It is one of the techniques for consolidating variables and for generating hypotheses about relationship among IVs to reveal underlying structure. Advantage of EFA is to deal with multicollinearity among IVs which cause bias in estimation of regression coefficient. This research applied EFA in the analysis of impact factor to explore a pattern among 18 impact factors as specified in Alberta benchmarking questionnaire. This technique also provides an evaluation of a relative impact of the groups of factors to construction productivity (CPM index) due to the evidence of high multicollinearity among factors. In brief, steps in EFA include selecting and measuring a group of variables, preparing correlation matrix, determining the number of components or factors to be considered, extracting a set of components or factors from the correlation matrix, in some case it includes rotating the components to increase interpretability, and finally interpreting the results (Tabachnick& Fidell, 2001).

Principle Component Analysis (PCA) is the most common used EFA extraction technique. PCA partitions the sum of the variances for the original variables by first finding the linear combination of the variables that accounts for the maximum amount of variance. Once the first component is extracted, the following component that is orthogonal to the first component is extracted to account for the next largest amount of variance that was not explained by the first extracted component. This extraction continues till all of variance is explained. As many components as variables are extracted in order to account for 100% of the variance. This study follows Kaiser's rule which states that factors having eigenvalues greater than 1 should be retained as important components. Then, due to the perception that the components (groups of impact factor) are correlated with one another, oblique rotation was conducted to improve the interpretability of the components (low intercorrelation among components).

Appendix E: Data Analysis Results

E.1 ANALYSIS OF ALBERTA METRICS (REFER TO CHAPTER 5)

Codebook

Variables	Descriptions
A_E_Peak	Actual/ Estimated Peak Workforce
budgfact	Project Budget Factor
ConCostPerWH	Construction Cost/ Total Field Work Hours ($/ WH)
congrow	Construction Phase Cost Growth
costgrow	Project Cost Growth
devfact	Development Change Cost Factor
Dir_Congrow	Construction Direct Cost Growth
Ind_Congrow	Construction Indirect Cost Growth
modper	Total Cost of Modules/ Total Proejct Cost (%)
P_con_ind_dir_cost	Construction Indirect/ Direct Cost (%)
P_con_ind_dir_wh	Construction Indirect/ Direct Work Hours (%)
P_Ind_TIC	Construction Indirect Cost/ Total Project Cost (%)
P_scaffwh_dirwh	Scaffolding Work Hours/ Construction Direct Work Hours (%)
PerContin	Contingency Budget/ Total Actual Project cost (%)
AdjProjCost_ov2007M	Total Project Cost ($M CDN, in 2007 Dollars)
rewfact	Rework Factor
ScaffWh_Direct	Scaffolding Wok Hours/ Construction Direct Work Hours (%)
schdfact	Project Schedule Factor
schdgrow	Project Schedule Growth
scpfact	Scope Change Cost Factor
tconcp_a_e	Actual/ Estimated Concrete Productivity Rate
tconuc_a_e	Actual/ Estimated Total Installed Unit Cost of Conctete
TotalBorep3_a_e	Actual/ Estimated Total Piping (Small& Large Bore) Productivity Rate
totalboreuc2_a_e	Actual/ Estimated Total Installed Unit Cost of Piping (Small& Large Bore)
tssteeluc_a_e	Actual/ Estimated Total Installed Unit Cost of Structural Steel
tsteel_a_e	Actual/ Estimated Structural Steel Productivity Rate

- **Test of Normality for Alberta Specific Metrics**

Alberta Specific Metrics	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
1. Construction indirect/Direct cost (%)	.150	18	.200	.915	18	.104
2. Construction indirect/Direct work hours (%)	.155	21	.200	.932	21	.150
3. Construction direct cost/TIC (%)	.212	18	.032	.912	18	.094
4. Direct construction cost growth	.193	16	.114	.943	16	.382
5. Indirect construction cost growth	.170	16	.200	.918	16	.155
6. Accuracy of workforce predictability	.240	22	.002	.825	22	.001
7. Scaffolding work hours/Direct work hours (%)	.257	19	.002	.818	19	.002
8. Modularization cost/Total project cost (%)	.194	36	.001	.917	36	.011
9. Offsite construction labor Hours/Total construction hours (%)	.155	33	.044	.908	33	.009
10. Overtime work hours/Total field work hours (%)	.316	14	.000	.677	14	.000
11. Percentage of work outdoor in winter	.159	18	.200	.968	18	.762
12. Estimating accuracy of total concrete productivity (WH/metric ton)	.218	9	.200	.814	9	.030
13. Estimating accuracy of total concrete unit cost ($\$/m^3$)	.263	10	.049	.779	10	.008
14. Estimating accuracy of total steel productivity	.185	17	.125	.950	17	.454
15. Estimating accuracy of total steel unit cost ($/metric ton)	.134	15	.200	.916	15	.167
16. Estimating accuracy of large bore piping productivity (WH/meter)	.133	10	.200	.978	10	.956
17. Estimating accuracy of large bore piping ($/meter)	.283	8	.059	.852	8	.100

Note: Shaded cells indicate non normal distribution of metrics

E.2 COMPARISON OF PROJECT PERFORMANCE AND PRODUCTIVITY BETWEEN ALBERTA AND U.S. PROJECTS (REFER TO SECTION 5.4)

E.2.1 Comparison of Project Performance between Alberta and U.S. Projects

a) Test Assumptions of T-test

Descriptive Statistics

Location		N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
								Statistic	Std. Error	Statistic	Std. Error
Alberta	AdjProjCost_ov2007M	23	3.32	1204.86	367.83	399.22	159373.11	.99	.48	-.18	.93
	concost_wh	14	40.68	318.43	144.35	73.07	5339.68	.95	.60	1.16	1.15
	PerContin	17	4.15	13.15	8.04	2.69	7.23	.24	.55	-.79	1.06
	costgrow	24	-.27	.98	.19	.32	.10	.65	.47	.23	.92
	budgfact	24	.75	2.00	1.13	.29	.08	1.26	.47	2.20	.92
	desgrow	10	.00	9.00	2.40	3.89	15.16	1.09	.69	-.96	1.33
	congrow	19	-.36	.87	.12	.33	.11	.66	.52	.27	1.01
	schdgrow	24	-.15	.92	.17	.22	.05	1.73	.47	4.74	.92
	schdfact	24	.00	1.00	.63	.49	.24	-.55	.47	-1.86	.92
	conscgro	22	.00	8.00	.86	2.08	4.31	2.58	.49	6.53	.95
	devfact	11	-.04	.32	.06	.09	.01	2.55	.66	7.62	1.28
	scpfact	13	-.11	.19	.02	.07	.00	.86	.62	4.16	1.19
	costfact	15	-.15	.36	.06	.11	.01	1.32	.58	3.53	1.12
	rewfact	11	.01	.17	.04	.05	.00	2.74	.66	7.96	1.28
	Valid N (listwise)	4									
U.S.	AdjProjCost_ov2007M	154	50.27	830.91	166.36	139.47	19451.21	2.55	.20	7.85	.39
	concost_wh	27	19.42	96.23	52.23	21.04	442.82	.73	.45	-.37	.87
	PerContin	29	.77	17.92	7.73	3.58	12.80	.47	.43	1.16	.85
	costgrow	153	-.40	.47	.03	.15	.02	.33	.20	.46	.39
	budgfact	154	.59	1.35	.97	.12	.01	.32	.20	1.31	.39
	desgrow	80	.00	9.00	1.56	2.57	6.63	1.60	.27	1.39	.53
	congrow	129	-.40	1.26	.08	.27	.07	1.49	.21	3.61	.42
	schdgrow	151	-.47	.75	.03	.15	.02	1.07	.20	5.43	.39
	schdfact	151	.00	1.00	.50	.50	.25	.01	.20	-2.03	.39
	conscgro	92	.00	8.00	1.78	2.71	7.34	1.24	.25	.02	.50
	devfact	7	.00	.17	.04	.06	.00	2.05	.79	4.50	1.59
	scpfact	10	.00	.13	.05	.05	.00	.80	.69	-1.12	1.33
	costfact	91	-.28	.51	.06	.11	.01	1.33	.25	6.81	.50
	rewfact	54	.00	.29	.05	.06	.00	2.70	.32	7.05	.64
	Valid N (listwise)	1									

C) T-Tests Results between Alberta and U.S. Project performance

Independent Samples Test

Metrics		Levene's Test F	Levene's Test Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI Lower	95% CI Upper
AdjProjCost_ov2007M	Equal variances assumed	77.350	.000	4.683	175	.000	201.471	43.024	116.559	286.383
	Equal variances not assumed			2.399	22.808	.025	201.471	83.997	27.628	375.314
concost_wh	Equal variances assumed	14.739	.000	6.140	39	.000	92.12	15.00	61.77	122.46
	Equal variances not assumed			4.619	14.129	.000	92.12	19.95	49.38	134.86
PerContin	Equal variances assumed	1.053	.310	.309	44	.759	.309	1.003	-1.711	2.330
	Equal variances not assumed			.332	41.128	.741	.309	.931	-1.570	2.189
costgrow	Equal variances assumed	32.037	.000	4.372	175	.000	.174	.040	.095	.252
	Equal variances not assumed			2.641	24.644	.014	.174	.066	.038	.309
budgfact	Equal variances assumed	38.056	.000	5.000	176	.000	.167	.033	.101	.233
	Equal variances not assumed			2.822	24.272	.009	.167	.059	.045	.289
desgrow	Equal variances assumed	6.362	.013	.912	88	.364	.837	.919	-.988	2.663
	Equal variances not assumed			.662	10.008	.523	.837	1.264	-1.979	3.654
congrow	Equal variances assumed	1.789	.183	.661	146	.509	.045	.068	-.089	.179
	Equal variances not assumed			.567	21.641	.577	.045	.079	-.120	.210
schdgrow	Equal variances assumed	6.191	.014	3.838	173	.000	.136	.035	.066	.206
	Equal variances not assumed			2.921	26.507	.007	.136	.046	.040	.231
schdfact	Equal variances assumed	9.891	.002	1.166	173	.245	.128	.110	-.089	.345
	Equal variances not assumed			1.178	31.011	.248	.128	.109	-.094	.350
conscgro	Equal variances assumed	5.443	.021	-1.488	112	.140	-.919	.618	-2.142	.305
	Equal variances not assumed			-1.750	40.027	.088	-.919	.525	-1.980	.142
devfact	Equal variances assumed	.133	.720	.415	16	.684	.017	.040	-.068	.101
	Equal variances not assumed			.455	15.926	.655	.017	.036	-.061	.094
scpfact	Equal variances assumed	.001	.976	-1.183	21	.250	-.030	.025	-.082	.023
	Equal variances not assumed			-1.226	20.999	.234	-.030	.024	-.081	.021
costfact	Equal variances assumed	.001	.976	-.058	104	.954	-.002	.030	-.061	.058
	Equal variances not assumed			-.056	18.310	.956	-.002	.031	-.067	.064
rewfact	Equal variances assumed	.583	.448	-.238	63	.813	-.005	.020	-.045	.035
	Equal variances not assumed			-.296	18.959	.770	-.005	.016	-.039	.029

E.2.2 Comparison of Construction Productivity between Alberta and U.S. Projects

Codebook

Variables	Descriptions
cabtrayp	Cable Tray Construction Productivity (WH/LM)
elheatp	Electrical Heat Tracing Construction Productivity (WH/LM)
exavp	Exposed or Above Ground Conduit Construction Productivity (WH/LM)
groundp	Grounding (Electrical) Construction Productivity (WH/LM)
ins_lop	Instrumentation- Loop Construction Productivity (WH/Count)
ins_tap	Instrumentation- Devices Construction Productivity (WH/Count)
insupip	Insulation Piping Construction Productivity (WH/LM)
lightp	Lighting Construction Productivity (WH/Each)
miscp	Miscellaneous Steel Construction Productivity Rate (WH/MT)
piprackp	Steel Pipe Racks& Utility Bridges Construction Productivity Rate (WH/MT)
powconp	Power and Control Cable (1k and above) Construction Productivity (WH/LM)
structp	Structural Steel Construction Productivity Rate (WH/MT)
tconcp	Total Concrete Construction Productivity Rate (WH/CM)
tcoonp	Total Conduit Construction Productivity (WH/LM)
tequipp	Total Electrical Equipment Construction Productivity (WH/Each)
Tlboreisp	Total Large Bore ISBL (>2.5") Construction Productivity (WH/LM)
tlborep	Total Large Bore OSBL Piping Construction Productivity Rate (WH/LM)
tsborep_all	Total Small Bore (<2.5") Construction Productivity (WH/LM)
tsteelp	Total Steel Construction Productivity Rate (WH/MT)
twirep	Total Wire and Cable Construction Productivity (WH/LM)

a) Descriptive Statistics

Location		N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
								Statistic	Std. Error	Statistic	Std. Error
Alberta	tconcp	12	6.571	41.504	19.394	11.187	125.140	.962	.637	-.276	1.232
	structp	11	5.733	168.000	58.250	47.435	2250.070	1.214	.661	1.835	1.279
	piprackp	6	10.239	88.936	50.499	33.878	1147.685	-.126	.845	-2.495	1.741
	miscp	9	3.680	190.494	88.099	60.095	3611.443	.052	.717	-.372	1.400
	tsteelp	21	5.733	168.000	53.947	41.882	1754.074	1.249	.501	1.445	.972
	cabtrayp	9	.414	8.847	2.791	2.854	8.146	1.610	.717	1.740	1.400
	twirep	11	.133	.933	.505	.297	.088	.324	.661	-1.411	1.279
	ins_tap	9	2.694	45.769	13.374	16.255	264.232	1.648	.717	1.122	1.400
	Tlboreisp	8	2.920	25.769	12.141	8.340	69.555	.592	.752	-1.125	1.481
	tlborep	7	.447	19.108	8.071	6.754	45.614	.787	.794	-.451	1.587
	insupip	16	.056	7.020	1.900	2.003	4.011	1.199	.564	1.308	1.091
U.S.	tconcp	32	.646	33.752	14.437	8.436	71.167	1.048	.414	.459	.809
	structp	22	16.383	113.105	42.388	26.786	717.472	1.448	.491	1.519	.953

Location		N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
								Statistic	Std. Error	Statistic	Std. Error
	piprackp	25	13.882	116.567	35.243	26.367	695.193	2.423	.464	5.760	.902
	miscp	26	17.637	154.106	61.677	30.082	904.901	.961	.456	2.494	.887
	tsteelp	32	15.789	108.921	42.414	22.090	487.967	1.374	.414	1.786	.809
	cabtrayp	27	1.148	6.890	3.137	1.760	3.097	.888	.448	-.382	.872
	twirep	22	.067	2.222	.318	.446	.199	4.050	.491	17.580	.953
	ins_tap	22	2.532	40.872	13.533	9.763	95.312	1.057	.491	1.296	.953
	tsborep_all	28	1.666	23.244	6.698	4.021	16.167	2.757	.441	10.319	.858
	Tlboreisp	27	3.281	43.677	13.819	10.084	101.694	1.529	.448	2.046	.872
	insupip	15	.577	3.701	1.928	.848	.720	.478	.580	.003	1.121

c) T-Test Results on Construction Productivity

Independent Samples Test

Metrics		Levene's Test		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI*	
									Lower	Upper
tconcp	Equal variances assumed	2.034	.161	1.585	42	.120	4.957	3.126	-1.353	11.266
	Equal variances not assumed			1.393	15.935	.183	4.957	3.557	-2.586	12.500
structp	Equal variances assumed	3.259	.081	1.234	31	.226	15.863	12.855	-10.356	42.081
	Equal variances not assumed			1.030	13.282	.321	15.863	15.400	-17.336	49.061
piprackp	Equal variances assumed	2.216	.147	1.207	29	.237	15.256	12.641	-10.597	41.110
	Equal variances not assumed			1.031	6.531	.339	15.256	14.802	-20.260	50.773
miscp	Equal variances assumed	8.449	.006	1.729	33	.093	26.422	15.280	-4.666	57.510
	Equal variances not assumed			1.265	9.425	.236	26.422	20.882	-20.495	73.338
tsteelp	Equal variances assumed	7.835	.007	1.309	51	.196	11.533	8.812	-6.157	29.223
	Equal variances not assumed			1.160	27.380	.256	11.533	9.939	-8.846	31.912
cabtrayp	Equal variances assumed	2.193	.148	-.434	34	.667	-.346	.797	-1.965	1.273
	Equal variances not assumed			-.342	10.106	.739	-.346	1.010	-2.593	1.901
twirep	Equal variances assumed	.043	.838	1.251	31	.220	.187	.149	-.118	.491
	Equal variances not assumed			1.428	28.198	.164	.187	.131	-.081	.454
ins_tap	Equal variances assumed	3.098	.089	-.034	29	.973	-.159	4.714	-9.800	9.481
	Equal variances not assumed			-.027	10.449	.979	-.159	5.804	-13.017	12.699
tsborep_all	Equal variances assumed	1.264	.269	-.275	31	.785	-.563	2.045	-4.734	3.607
	Equal variances not assumed			-.225	4.848	.831	-.563	2.500	-7.051	5.925
Tlboreisp	Equal variances assumed	.054	.818	-.428	33	.671	-1.678	3.921	-9.655	6.299

Independent Samples Test

Metrics		Levene's Test F	Levene's Test Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI* Lower	95% CI* Upper
	Equal variances not assumed			-.475	13.687	.642	-1.678	3.530	-9.266	5.909
tlborep	Equal variances assumed	1.385	.260	.452	13	.659	1.311	2.898	-4.949	7.571
	Equal variances not assumed			.439	10.049	.670	1.311	2.984	-5.334	7.956
insupip	Equal variances assumed	8.282	.007	-.050	29	.961	-.028	.559	-1.172	1.116
	Equal variances not assumed			-.051	20.486	.960	-.028	.547	-1.166	1.110
AdjProjCost_ov2007M	Equal variances assumed	28.165	.000	3.828	60	.000	337.602	88.182	161.212	513.991
	Equal variances not assumed			4.033	40.199	.000	337.602	83.716	168.431	506.772

Note: 95% CI* indicates 95% confidence interval of the difference

E.2.3 Comparison of Engineering Productivity between Alberta and U.S. Projects

Codebook

Variables	Descriptions
etconcp	Total Concrete Engineering Productivity Rate (WH/CM)
etfondp	Total Foundation Engineering Productivity Rate (WH/CM)
estructp	Structural Steel Engineering Productivity Rate (WH/MT)
epipep	Steel Pipe Racks& Utility BridgesEngineering Productivity Rate (WH/MT)
etstpipp	Combined Structural Steel, Pipe Racks and Utility Bridges Engineering Productivity Rate (WH/MT)
emiscp	Miscellaneous Steel Engineering Productivity Rate (WH/MT)
etstelp	Total Steel Engineering Productivity Rate (WH/MT)
esmallp	Total Small Bore Piping Engineering Productivity Rate (WH/LM)
elgt3p	Total Large Bore Piping Engineering Productivity Rate (WH/LM)
etotpipp	Total Piping (Small & Large Bore) Engineering Productivity Rate (WH/LM)
etelqpp	Total Electrical Equipment (WH/Each)
ecablep	Cable tray Engineering Productivity Rate (WH/LM)
ewirep	Wire & Cable Engineering Productivity Rate (WH/LM)
etotp	Total Equipment (total of above except Vendor) Engineering Productivity Rate (WH/Each)
eins_lop	Instrumentation-Loops (WH/Count)
eins_tap	Instrumentation- Tagged Devices(WH/Count)
eins_iop	Instrumentation- I/O (WH/Count)

a) Descriptive Statistics

Descriptive Statistics

Location		N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
								Statistic	Std. Error	Statistic	Std. Error
Alberta	etfondp	10	.852	7.225	2.770	1.852	3.430	1.679	.687	3.394	1.334
	etconcp	17	.291	24.986	5.917	7.611	57.932	1.823	.550	2.146	1.063
	etstpipp	10	3.068	47.619	17.692	12.157	147.785	1.831	.687	4.273	1.334
	emiscp	11	4.677	66.667	36.149	23.744	563.763	.243	.661	-1.864	1.279
	etstelp	19	4.669	86.667	23.082	20.183	407.341	2.283	.524	5.357	1.014
	esmallp	10	.148	2.332	1.004	.808	.652	.732	.687	-.457	1.334
	elgt3p	12	.020	3.268	.878	.995	.989	1.617	.637	2.159	1.232
	etotpipp	22	.038	6.846	1.597	1.557	2.423	2.127	.491	5.574	.953
	etelqpp	10	1.040	189.320	67.210	74.668	5575.319	.919	.687	-1.144	1.334
	ecablep	10	.008	1.969	.549	.703	.494	1.643	.687	1.257	1.334
	ewirep	12	.011	.721	.168	.231	.054	1.953	.637	2.751	1.232
	etotp	17	38.119	429.279	152.305	106.061	11248.949	1.254	.550	1.492	1.063
	eins_lop	18	3.745	78.075	31.585	21.677	469.877	.646	.536	-.132	1.038
	eins_tap	20	1.408	44.232	15.449	11.585	134.220	1.031	.512	.782	.992
	eins_iop	17	5.336	67.000	18.864	16.391	268.652	1.856	.550	3.633	1.063
U.S.	etfondp	20	.329	20.272	3.234	5.174	26.773	2.743	.512	7.071	.992
	etconcp	31	.078	20.272	4.525	5.350	28.623	1.732	.421	2.354	.821
	estructp	31	.706	58.728	8.157	10.527	110.807	3.924	.421	18.486	.821
	etstpipp	36	.706	58.728	8.879	11.250	126.554	3.301	.393	12.235	.768
	emiscp	29	.053	88.897	11.823	16.348	267.254	3.959	.434	18.605	.845
	etstelp	56	.792	60.544	10.961	10.692	114.315	2.506	.319	8.307	.628
	esmallp	23	.391	8.202	2.075	1.664	2.770	2.449	.481	7.914	.935
	elgt3p	26	.656	10.298	2.577	2.092	4.376	2.351	.456	6.923	.887
	etotpipp	61	.099	9.771	1.974	1.657	2.746	2.518	.306	8.946	.604
	etelqpp	19	3.416	40.073	19.325	11.975	143.394	.527	.524	-1.057	1.014
	ecablep	22	.112	6.890	1.723	1.785	3.187	1.445	.491	1.938	.953
	ewirep	23	.002	.292	.077	.081	.007	1.724	.481	2.506	.935
	etotp	36	7.830	1036.200	191.863	227.866	51923.056	2.443	.393	6.029	.768
	eins_lop	29	.800	2411.000	117.024	446.834	199660.44	5.189	.434	27.405	.845
	eins_tap	54	.460	71.300	11.309	12.714	161.641	2.590	.325	9.014	.639
	eins_iop	44	.657	61.623	9.195	10.799	116.617	3.051	.357	12.419	.702

Note: Engineering discipline with sample size less than 5 are suppressed.

b) T-Test Results on Engineering Productivity

Independent Samples Test

Metrics		Levene's Test		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI* Lower	95% CI* Upper
etfondp	Equal variances assumed	1.863	.183	-.273	28	.787	-.465	1.700	-3.947	3.018
	Equal variances not assumed			-.358	26.334	.723	-.465	1.297	-3.128	2.199
etconcp	Equal variances assumed	1.578	.215	.740	46	.463	1.392	1.880	-2.393	5.177
	Equal variances not assumed			.669	24.871	.510	1.392	2.081	-2.895	5.680
etstpipp	Equal variances assumed	.180	.673	2.155	44	.037	8.813	4.090	.571	17.055
	Equal variances not assumed			2.060	13.593	.059	8.813	4.277	-.386	18.012
emiscp	Equal variances assumed	7.572	.009	3.697	38	.001	24.326	6.580	11.006	37.647
	Equal variances not assumed			3.128	13.761	.008	24.326	7.776	7.621	41.032
etstelp	Equal variances assumed	5.104	.027	3.342	73	.001	12.121	3.626	4.894	19.348
	Equal variances not assumed			2.501	21.527	.020	12.121	4.846	2.059	22.183
esmallp	Equal variances assumed	1.456	.237	-1.927	31	.063	-1.071	.556	-2.205	.063
	Equal variances not assumed			-2.486	30.451	.019	-1.071	.431	-1.951	-.192
elgt3p	Equal variances assumed	2.162	.150	-2.663	36	.012	-1.699	.638	-2.993	-.405
	Equal variances not assumed			-3.393	35.909	.002	-1.699	.501	-2.715	-.683
etotpipp	Equal variances assumed	.071	.791	-.929	81	.356	-.377	.406	-1.184	.430
	Equal variances not assumed			-.957	39.371	.344	-.377	.394	-1.174	.420
etelqpp	Equal variances assumed	46.993	.000	2.773	27	.010	47.885	17.270	12.450	83.320
	Equal variances not assumed			2.014	9.244	.074	47.885	23.771	-5.673	101.444
ecablep	Equal variances assumed	6.161	.019	-1.996	30	.055	-1.175	.588	-2.376	.027
	Equal variances not assumed			-2.664	29.707	.012	-1.175	.441	-2.075	-.274
etotp	Equal variances assumed	2.364	.130	-.679	51	.500	-39.558	58.237	-156.473	77.357
	Equal variances not assumed			-.862	51.000	.393	-39.558	45.869	-131.645	52.529
eins_lop	Equal variances assumed	2.748	.104	-.807	45	.424	-85.439	105.838	-298.608	127.730
	Equal variances not assumed			-1.028	28.212	.313	-85.439	83.132	-255.670	84.792
eins_tap	Equal variances assumed	.022	.883	1.273	72	.207	4.140	3.253	-2.344	10.624
	Equal variances not assumed			1.329	37.085	.192	4.140	3.115	-2.172	10.451
eins_iop	Equal variances assumed	4.557	.037	2.695	59	.009	9.669	3.588	2.490	16.848
	Equal variances not assumed			2.251	21.591	.035	9.669	4.296	.750	18.588

Note: 95% CI* indicates 95% confidence interval of the difference

E.3 ANALYSIS OF PROJECT PERFORMANCE BY PROJECT CHARACTERISTICS, MANAGEMENT/ BEST PRACTICES (REFER TO SECTION 6.1)

- **Actual/ Estimated Peak Construction Workforce vs. Project Cost Growth**

Coefficients[a]

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95% Confidence Interval for B Lower Bound	95% Confidence Interval for B Upper Bound
1 (Constant)	-.601	.160		-3.767	.001	-.937	-.266
A_E_Peak	.641	.118	.787	5.417	.000	.392	.889

a. Dependent Variable: costgrow

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.787[a]	.620	.599	.209196	1.488

a. Predictors: (Constant), A_E_Peak

b. Dependent Variable: costgrow

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.284	1	1.284	29.342	.000[a]
	Residual	.788	18	.044		
	Total	2.072	19			

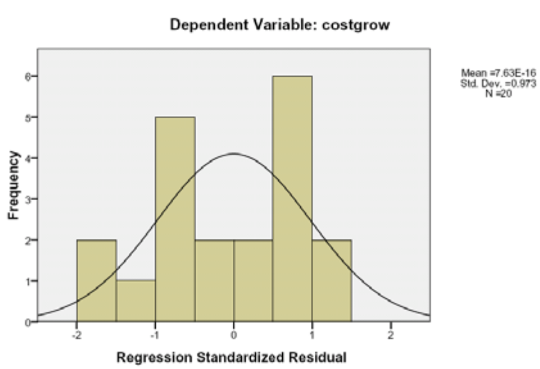
a. Predictors: (Constant), A_E_Peak

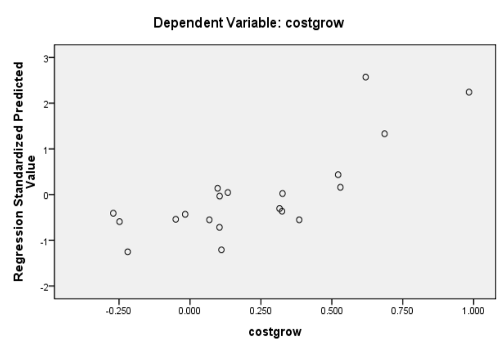
b. Dependent Variable: costgrow

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-.09992	.89353	.22528	.259970	20
Residual	-.389876	.302943	.000000	.203616	20
Std. Predicted Value	-1.251	2.570	.000	1.000	20
Std. Residual	-1.864	1.448	.000	.973	20

a. Dependent Variable: costgrow





- **Actual/ Estimated Peak Construction Workforce vs. Project Schedule Growth**

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.543[a]	.295	.258	.193193	1.606

a. Predictors: (Constant), A_E_Peak

b. Dependent Variable: schdgrow

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.297	1	.297	7.964	.011[a]
	Residual	.709	19	.037		
	Total	1.006	20			

a. Predictors: (Constant), A_E_Peak

b. Dependent Variable: schdgrow

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.259	.152		-1.699	.106
	A_E_Peak	.317	.112	.543	2.822	.011

a. Dependent Variable: schdgrow

Coefficients[a]

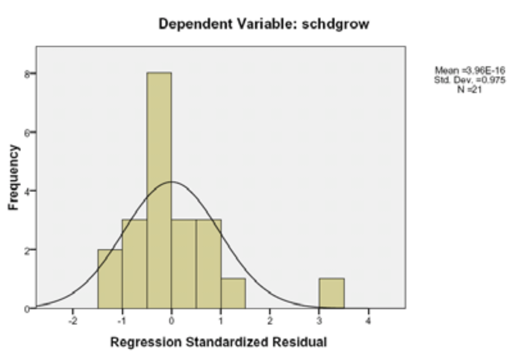
Model		95% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	-.577	.060
	A_E_Peak	.082	.553

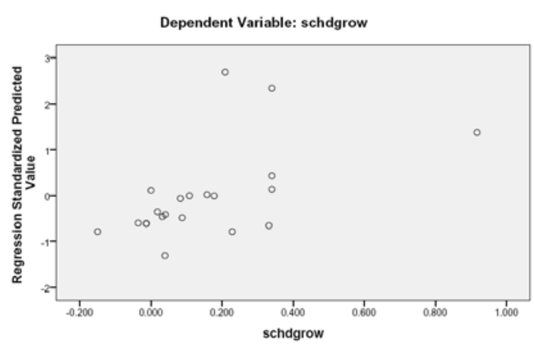
a. Dependent Variable: schdgrow

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-.00478	.48172	.15418	.121915	21
Residual	-.273158	.595319	.000000	.188302	21
Std. Predicted Value	-1.304	2.687	.000	1.000	21
Std. Residual	-1.414	3.081	.000	.975	21

a. Dependent Variable: schdgrow





- **Construction Indirect Cost Growth vs. Adjusted Total Project Cost ($M CDN)**

Correlations

		schdfact	P_con_ind_dir_wh
Pearson Correlation	schdfact	1.000	-.446
	P_con_ind_dir_wh	-.446	1.000
Sig. (1-tailed)	schdfact	.	.028
	P_con_ind_dir_wh	.028	.
N	schdfact	19	19
	P_con_ind_dir_wh	19	19

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.446[a]	.199	.152	.341927	2.191

a. Predictors: (Constant), P_con_ind_dir_wh

b. Dependent Variable: schdfact

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.495	1	.495	4.230	.055[a]
	Residual	1.988	17	.117		
	Total	2.482	18			

a. Predictors: (Constant), P_con_ind_dir_wh

b. Dependent Variable: schdfact

Coefficients[a]

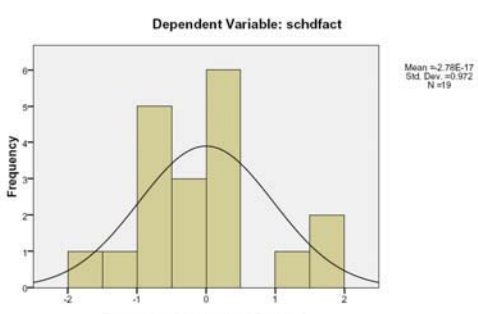
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.433	.182		7.875	.000
	P_con_ind_dir_wh	-.010	.005	-.446	-2.057	.055

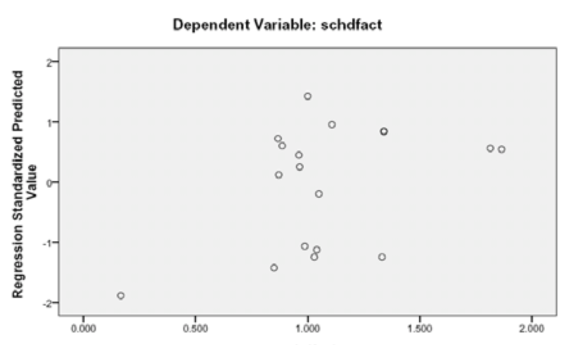
a. Dependent Variable: schdfact

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.78293	1.33218	1.09535	.165753	19
Residual	-.616911	.679586	.000000	.332294	19
Std. Predicted Value	-1.885	1.429	.000	1.000	19
Std. Residual	-1.804	1.988	.000	.972	19

a. Dependent Variable: schdfact





- **Construction Indirect WH/ Direct WH(%) Project Schedule Factor**

Correlations

		schdfact	P_con_ind_dir_wh
Pearson Correlation	schdfact	1.000	-.446
	P_con_ind_dir_wh	-.446	1.000
Sig. (1-tailed)	schdfact	.	.028
	P_con_ind_dir_wh	.028	.
N	schdfact	19	19
	P_con_ind_dir_wh	19	19

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.446[a]	.199	.152	.341927	2.191

a. Predictors: (Constant), P_con_ind_dir_wh

b. Dependent Variable: schdfact

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.495	1	.495	4.230	.055[a]
	Residual	1.988	17	.117		
	Total	2.482	18			

a. Predictors: (Constant), P_con_ind_dir_wh

b. Dependent Variable: schdfact

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.433	.182		7.875	.000
	P_con_ind_dir_wh	-.010	.005	-.446	-2.057	.055

a. Dependent Variable: schdfact

Coefficients[a]

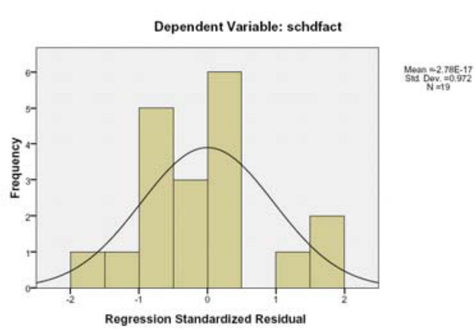
Model		95% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	1.049	1.817
	P_con_ind_dir_wh	-.020	.000

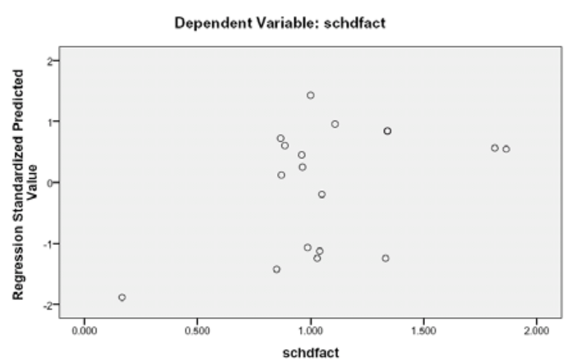
a. Dependent Variable: schdfact

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.78293	1.33218	1.09535	.165753	19
Residual	-.616911	.679586	.000000	.332294	19
Std. Predicted Value	-1.885	1.429	.000	1.000	19
Std. Residual	-1.804	1.988	.000	.972	19

a. Dependent Variable: schdfact





- **Percent Engineering Completed Before construction Start**

Linear

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.723	.523	.483	.198

The independent variable is perdsncn.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	.516	1	.516	13.164	.003
Residual	.470	12	.039		
Total	.986	13			

The independent variable is perdsncn.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
perdsncn	-.008	.002	-.723	-3.628	.003
(Constant)	.591	.142		4.158	.001

Quadratic

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.793	.629	.561	.182

The independent variable is perdsncn.

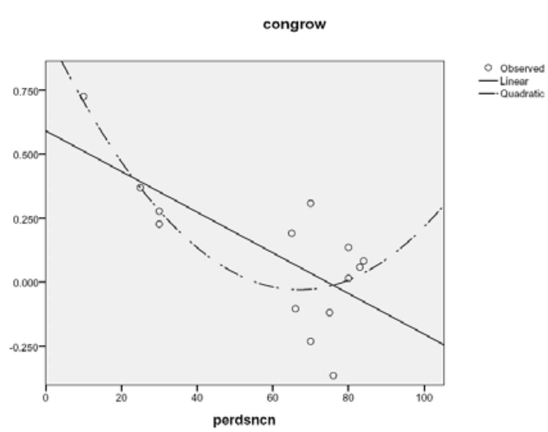
ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	.620	2	.310	9.316	.004
Residual	.366	11	.033		
Total	.986	13			

The independent variable is perdsncn.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
perdsncn	-.030	.013	-2.762	-2.367	.037
perdsncn ** 2	.000	.000	2.064	1.769	.105
(Constant)	.986	.259		3.811	.003



- **Construction Productivity Index (CPM Index) vs. Project Size ($M)**

Descriptive Statistics

	Mean	Std. Deviation	N
CPM Index	-.22246	1.059881	20
AdjProjCost_ov2007M	335.03	381.176	20

Correlations

		CPM Index	AdjProjCost_ov2007M
Pearson Correlation	CPM Index	1.000	-.364
	AdjProjCost_ov2007M	-.364	1.000
Sig. (1-tailed)	CPM Index	.	.057
	AdjProjCost_ov2007M	.057	.
N	CPM Index	20	20
	AdjProjCost_ov2007M	20	20

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.364[a]	.133	.084	1.014183	2.404

a. Predictors: (Constant), AdjProjCost_ov2007M_delout

b. Dependent Variable: CPM Index

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.829	1	2.829	2.751	.115[a]
	Residual	18.514	18	1.029		
	Total	21.344	19			

a. Predictors: (Constant), AdjProjCost_ov2007M_delout

b. Dependent Variable: CPM Index

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.117	.305		.382	.707	-.525	.758
	AdjProjCost_ov2007M	-.001	.001	-.364	-1.659	.115	-.002	.000

a. Dependent Variable: CPM Index

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-1.10306	.11336	-.22246	.385897	20
Residual	-1.615972	1.785886	.000000	.987133	20
Std. Predicted Value	-2.282	.870	.000	1.000	20
Std. Residual	-1.593	1.761	.000	.973	20

a. Dependent Variable: CPM Index

E.4 ANALYSIS OF PROJECT PERFORMANCE AND BEST PRACTICES (REFER TO SECTION 6.2)

a) Relationship of Project Performance and Best Practices

E.4.1 Descriptive Statistics of Practice Metrics

Descriptive Statistics

Location		N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
								Statistic	Std. Error	Statistic	Std. Error
Alberta	aitech	23	3.173	9.615	5.45926	1.557193	2.425	1.085	.481	.967	.935
	alignment	32	4.375	9.375	6.95047	1.644894	2.706	-.003	.414	-1.388	.809
	chgindex	26	4.300	9.766	7.75673	1.208964	1.462	-.755	.456	1.620	.887
	cntindex	26	.000	10.000	7.72954	2.392302	5.723	-1.981	.456	4.095	.887
	des_mnt	19	.714	9.286	6.48200	2.500314	6.252	-.807	.524	.010	1.014
	matmgmt	26	2.222	10.000	6.92865	2.258246	5.100	-.449	.456	-1.100	.887
	pdri	20	34.000	274.000	125.65000	70.265118	4937.187	.391	.512	-.893	.992
	plnstu	22	5.923	9.778	8.21095	1.109799	1.232	-.743	.491	.002	.953
	pp_mof	22	4.167	10.000	8.62118	1.611474	2.597	-1.103	.491	.953	.953
	pppindex	33	.825	9.191	5.10164	3.663198	13.419	-.213	.409	-1.955	.798
	pra	33	2.500	10.000	7.44618	1.574717	2.480	-1.314	.409	2.870	.798
	quamgmt	25	3.708	7.308	6.05604	.950924	.904	-.573	.464	-.271	.902
	sftindex	22	6.565	9.688	8.13341	.700367	.491	.001	.491	.461	.953
	tmbindex	32	1.625	9.426	7.26719	1.906334	3.634	-1.113	.414	1.240	.809
	WFP_overall	8	3.650	7.500	6.04062	1.297796	1.684	-.968	.752	.172	1.481

Location		N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
								Statistic	Std. Error	Statistic	Std. Error
U.S.	aitech	12	3.542	10.000	6.19650	2.018303	4.074	.654	.637	-.234	1.232
	alignment	5	4.000	10.000	8.00000	2.345208	5.500	-1.744	.913	3.322	2.000
	chgindex	95	2.730	10.000	8.27118	1.766923	3.122	-1.276	.247	1.499	.490
	cntindex	98	.000	9.571	5.89805	2.686170	7.216	-.866	.244	-.098	.483
	matmgmt	34	.000	10.000	7.25271	3.294118	10.851	-1.556	.403	1.125	.788
	plnstu	26	.000	10.000	7.23077	3.140799	9.865	-1.406	.456	1.154	.887
	pppindex	121	.000	10.000	7.64307	2.264260	5.127	-1.602	.220	2.481	.437
	quamgmt	13	2.500	8.385	6.01077	1.643467	2.701	-.828	.616	.497	1.191
	sftindex	131	1.390	10.000	9.38087	1.039861	1.081	-4.007	.212	26.168	.420
	tmbindex	145	.000	10.000	5.72695	3.177713	10.098	-.650	.201	-.718	.400

E.4.2 Regression Analysis of Best Practices and Project Performance

- **Project Cost Growth vs. PRA**

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.436[a]	.190	.147	.294890	1.664

a. Predictors: (Constant), pra

b. Dependent Variable: costgrow

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.388	1	.388	4.458	.048[a]
	Residual	1.652	19	.087		
	Total	2.040	20			

a. Predictors: (Constant), pra

b. Dependent Variable: costgrow

Coefficients[a]

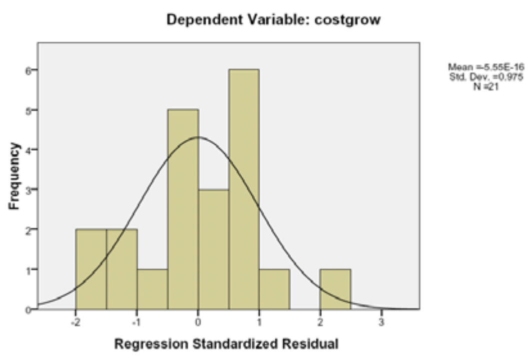
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.892	.321		2.783	.012
	pra	-.087	.041	-.436	-2.111	.048

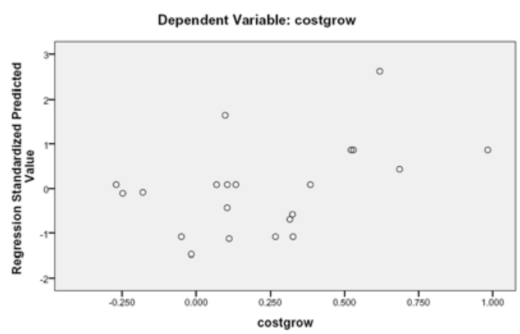
a. Dependent Variable: costgrow

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.02440	.59378	.22915	.139222	21
Residual	-.511773	.633784	.000000	.287423	21
Std. Predicted Value	-1.471	2.619	.000	1.000	21
Std. Residual	-1.735	2.149	.000	.975	21

a. Dependent Variable: costgrow





- **Project Cost Growth vs. PRA**

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.528[a]	.279	.246	.190863	1.220

a. Predictors: (Constant), cntindex

b. Dependent Variable: schdgrow

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.310	1	.310	8.504	.008[a]
	Residual	.801	22	.036		
	Total	1.111	23			

a. Predictors: (Constant), cntindex

b. Dependent Variable: schdgrow

Coefficients[a]

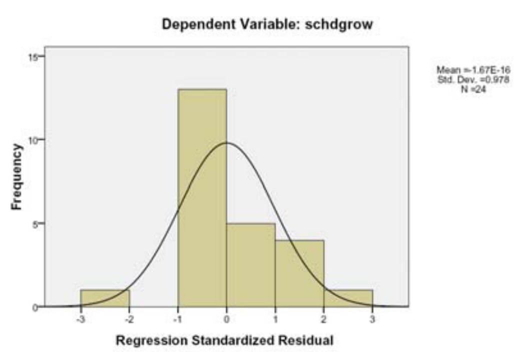
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.528	.129		4.086	.000
	cntindex	-.047	.016	-.528	-2.916	.008

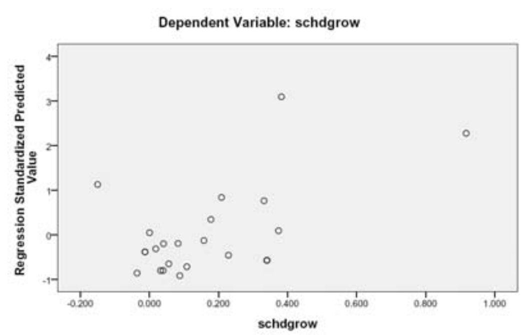
a. Dependent Variable: schdgrow

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.06191	.52821	.16872	.116060	24
Residual	-.449905	.484392	.000000	.186668	24
Std. Predicted Value	-.920	3.097	.000	1.000	24
Std. Residual	-2.357	2.538	.000	.978	24

a. Dependent Variable: schdgrow





- **Material Management vs. Project Cost Growth**

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.523[a]	.273	.239	.162242	1.460

a. Predictors: (Constant), matmgmt

b. Dependent Variable: conscgro

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.208	1	.208	7.895	.010[a]
	Residual	.553	21	.026		
	Total	.761	22			

a. Predictors: (Constant), matmgmt

b. Dependent Variable: conscgro

Coefficients[a]

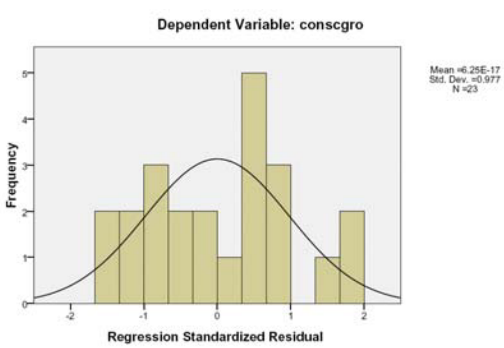
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.541	.113		4.774	.000
	matmgmt	-.043	.015	-.523	-2.810	.010

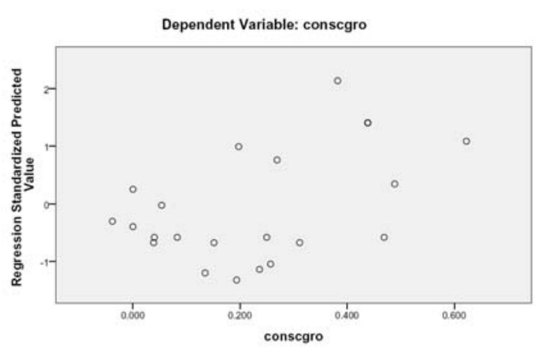
a. Dependent Variable: conscgro

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.10839	.44487	.23713	.097193	23
Residual	-.261618	.288374	.000000	.158512	23
Std. Predicted Value	-1.325	2.137	.000	1.000	23
Std. Residual	-1.613	1.777	.000	.977	23

a. Dependent Variable: conscgro





- **AI Tech. vs. Project Cost Growth**

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.617[a]	.381	.346	.264863	1.640

a. Predictors: (Constant), aitech

b. Dependent Variable: costgrow

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.776	1	.776	11.056	.004[a]
	Residual	1.263	18	.070		
	Total	2.038	19			

a. Predictors: (Constant), aitech

b. Dependent Variable: costgrow

Coefficients[a]

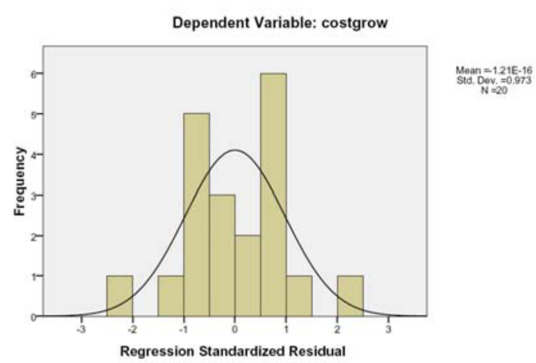
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.941	.223		4.226	.001
	aitech	-.129	.039	-.617	-3.325	.004

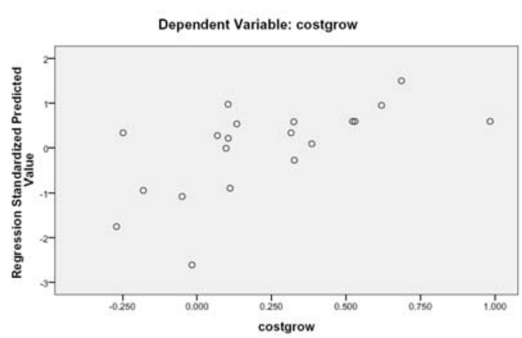
a. Dependent Variable: costgrow

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-.30117	.53122	.22724	.202045	20
Residual	-.543540	.636734	.000000	.257799	20
Std. Predicted Value	-2.615	1.505	.000	1.000	20
Std. Residual	-2.052	2.404	.000	.973	20

a. Dependent Variable: costgrow





- **CPM Index vs. Project Size ($M CDN)**

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.364[a]	.133	.084	1.014183	2.404

a. Predictors: (Constant), AdjProjCost_ov2007M_delout

b. Dependent Variable: CPM Index

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.829	1	2.829	2.751	.115[a]
	Residual	18.514	18	1.029		
	Total	21.344	19			

a. Predictors: (Constant), AdjProjCost_ov2007M_delout

b. Dependent Variable: CPM Index

Coefficients[a]

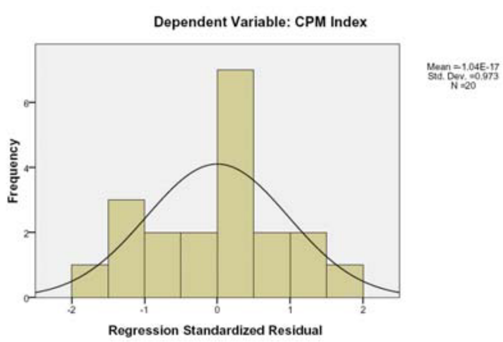
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.117	.305		.382	.707
	AdjProjCost_ov2007M_delout	-.001	.001	-.364	-1.659	.115

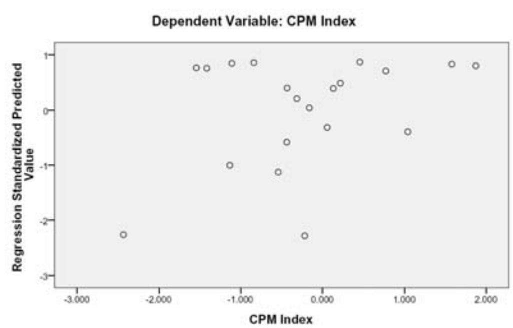
a. Dependent Variable: CPM Index

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-1.10306	.11336	-.22246	.385897	20
Residual	-1.615972	1.785886	.000000	.987133	20
Std. Predicted Value	-2.282	.870	.000	1.000	20
Std. Residual	-1.593	1.761	.000	.973	20

a. Dependent Variable: CPM Index



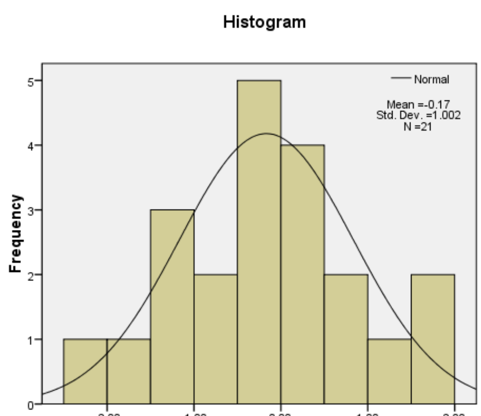


E.5 Results for Analysis of Impact Factors on CPM Index of Alberta Dataset (Refer to Sections 7.1 to 7.2, and 7.5)

Codebook

No.	Variables	Descriptions
1	actegconp	Percent engineering finished before construction start
2	busmconp	Amount of scheduled overtime
3	cplxconp	Project complexity
4	englconp	Quality of field supervision
5	engsconp	Quality of engineering
6	expeconp	Project team experience
7	laavconp	Labor availability
8	laskconp	Labor skill
9	maavconp	Material availability
10	overconp	Amount of schedule overtime
11	plnegconp	Percent engineering finished before project sanction
12	regsconp	Regulatory requirement
13	shutconp	Coordination for plant shutdown
14	sitcoconp	Site conditions
15	supeconp	Project team experience
16	turnconp	Project team turnover
17	upovconp	Amount of unplanned overtime
18	weconp	Weather conditions

E.5.1 Descriptive Statistics of Impact Factors and CPM Index



Metrics	N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
CPM Index	21	-2.00	1.87	-.1674	1.00228	1.005	.230	.501	-.213	.972
weconp	21	1	4	3.33	.796	.633	-1.364	.501	2.366	.972
laskconp	22	2	5	3.45	1.011	1.022	.136	.491	-.955	.953
laavconp	23	2	4	3.22	.736	.542	-.376	.481	-.975	.935
maavconp	22	2	4	3.27	.550	.303	.109	.491	-.264	.953
sitcoconp	21	2	4	3.43	.598	.357	-.476	.501	-.560	.972
cplxconp	22	3	5	3.27	.631	.398	2.232	.491	3.898	.953
regsconp	19	3	4	3.11	.315	.099	2.798	.524	6.509	1.014
expeconp	20	2	4	3.30	.733	.537	-.553	.512	-.834	.992
turnconp	15	2	4	3.27	.594	.352	-.091	.580	-.171	1.121
englconp	4	3	4	3.50	.577	.333	.000	1.014	-6.000	2.619
busmconp	17	3	5	3.76	.831	.691	.496	.550	-1.357	1.063
shutconp	11	1	4	3.09	.944	.891	-1.081	.661	1.206	1.279
supeconp	21	2	5	3.48	1.078	1.162	-.065	.501	-1.203	.972
overconp	17	2	4	3.12	.485	.235	.399	.550	1.905	1.063
upovconp	18	2	5	3.78	.808	.654	-.300	.536	.024	1.038
engsconp	13	2	5	3.23	.927	.859	.211	.616	-.546	1.191
plnegconp	13	2	5	3.31	.751	.564	.784	.616	1.223	1.191
actegconp	18	2	5	3.83	.985	.971	-.461	.536	-.606	1.038

E.5.2 Evaluate Sample Size (Refer to Section 7.5.1)

Descriptive Statistics

	Mean	Std. Deviation	N
CPM Index	.1709	1.02540	12
weconp	3.50	.674	12
actegconp	3.92	.900	12
expeconp	3.42	.793	12

Correlations

		CPM Index	weconp	actegconp	expeconp
Pearson Correlation	CPM Index	1.000	.446	.609	.130
	weconp	.446	1.000	.374	.595
	actegconp	.609	.374	1.000	.435
	expeconp	.130	.595	.435	1.000
Sig. (1-tailed)	CPM Index	.	.073	.018	.344
	weconp	.073	.	.115	.021
	actegconp	.018	.115	.	.079
	expeconp	.344	.021	.079	.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.726[a]	.527	.349	.82734	.527	2.966	3	8	.097	2.448

a. Predictors: (Constant), expeconp, actegconp, weconp

b. Dependent Variable: CPM Index

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6.090	3	2.030	2.966	.097[a]
	Residual	5.476	8	.684		
	Total	11.566	11			

a. Predictors: (Constant), expeconp, actegconp, weconp

b. Dependent Variable: CPM_Index

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-3.206	1.481		-2.164	.062		
	weconp	.700	.466	.460	1.500	.172	.629	1.589
	actegconp	.701	.312	.616	2.250	.055	.790	1.266
	expeconp	-.533	.408	-.412	-1.304	.228	.593	1.685

a. Dependent Variable: CPM_Index

E.5.3 Approach 1: Rank Relative Impact of Factors by Using Multiple Regression (Refer to Section 7.5.2)

Multiple regression with stepwise and listwise deletion

Descriptive Statistics

Metrics	Mean	Std. Deviation	N
CPM Index	-.5935	.60568	6
weconp	3.33	.816	6
laskconp	3.17	1.169	6
laavconp	3.00	.894	6
maavconp	3.33	.516	6
sitcoconp	3.67	.516	6
cplxconp	3.17	.408	6
regsconp	3.33	.516	6
expeconp	3.17	.753	6
turnconp	3.50	.548	6
supeconp	2.83	.983	6
overconp	3.33	.516	6
upovconp	3.67	.516	6
plnegconp	3.17	.753	6
actegconp	3.33	.816	6

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	actegconp	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	overconp	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: CPM Index

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.912[a]	.831	.789	.27798	.831	19.737	1	4	.011	
2	.987[b]	.974	.957	.12523	.143	16.710	1	3	.026	1.663

a. Predictors: (Constant), actegconp

b. Predictors: (Constant), actegconp, overconp

c. Dependent Variable: CPM Index

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.525	1	1.525	19.737	.011[a]
	Residual	.309	4	.077		
	Total	1.834	5			
2	Regression	1.787	2	.894	56.982	.004[b]
	Residual	.047	3	.016		
	Total	1.834	5			

a. Predictors: (Constant), actegconp

b. Predictors: (Constant), actegconp, overconp

c. Dependent Variable: CPM_Index

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-2.848	.520		-5.477	.005		
	actegconp	.676	.152	.912	4.443	.011	1.000	1.000
2	(Constant)	-4.195	.404		-10.376	.002		
	actegconp	.632	.069	.851	9.091	.003	.975	1.026
	overconp	.449	.110	.383	4.088	.026	.975	1.026

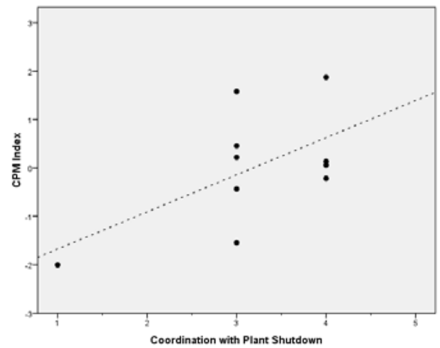
a. Dependent Variable: CPM_Index

E.5.4 Approach 2: Rank Relative Impact of Factors by Using Bivariate Relationship (Refer to Section 7.5.3, Example of the top three factors)

- **Simple regression of CPM index and *Coordination of plant shutdown***

Descriptive Statistics

	Mean	Std. Deviation	N
CPM_Index	.0112	1.19781	10
shutconp	3.20	.919	10



Correlations

		CPM_delout	shutconp
Pearson Correlation	CPM_Index	1.000	.588
	shutconp	.588	1.000
Sig. (1-tailed)	CPM_Index	.	.037
	shutconp	.037	.
N	CPM_Index	10	10
	shutconp	10	10

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.588[a]	.346	.264	1.02731	.346	4.235	1	8	.074	1.577

a. Predictors: (Constant), shutconp

b. Dependent Variable: CPM_Index

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.470	1	4.470	4.235	.074[a]
	Residual	8.443	8	1.055		
	Total	12.913	9			

a. Predictors: (Constant), shutconp

b. Dependent Variable: CPM_Index

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-2.443	1.236		-1.977	.083		
	shutconp	.767	.373	.588	2.058	.074	1.000	1.000

a. Dependent Variable: CPM_Index

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-1.6759	.6248	.0112	.70473	10
Residual	-1.40084	1.72189	.00000	.96856	10
Std. Predicted Value	-2.394	.871	.000	1.000	10
Std. Residual	-1.364	1.676	.000	.943	10

a. Dependent Variable: CPM_Index

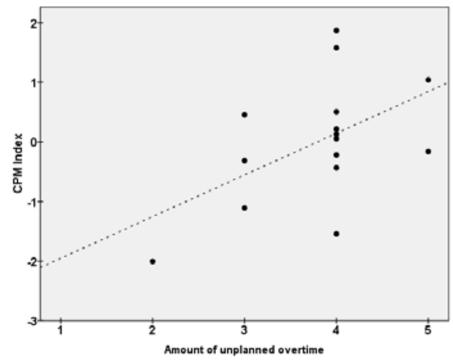
- ## Simple regression of CPM index and *Amount of unplanned overtime*

Descriptive Statistics

	Mean	Std. Deviation	N
CPM_Index	.0052	1.05579	15
upovconp	3.80	.775	15

Correlations

		CPM_Index	upovconp
Pearson Correlation	CPM_Index	1.000	.513
	upovconp	.513	1.000
Sig. (1-tailed)	CPM_Index	.	.025
	upovconp	.025	.
N	CPM_Index	15	15
	upovconp	15	15



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.513[a]	.263	.206	.94064	.263	4.637	1	13	.051	2.145

a. Predictors: (Constant), upovconp

b. Dependent Variable: CPM_Index

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.103	1	4.103	4.637	.051[a]
	Residual	11.502	13	.885		
	Total	15.606	14			

a. Predictors: (Constant), upovconp

b. Dependent Variable: CPM_Index

Coefficients[a]

Model		Unstandardized Coefficients: B	Unstandardized Coefficients: Std. Error	Standardized Coefficients: Beta	t	Sig.	Collinearity Statistics: Tolerance	Collinearity Statistics: VIF
1	(Constant)	-2.651	1.257		-2.109	.055		
	upovconp	.699	.325	.513	2.153	.051	1.000	1.000

a. Dependent Variable: CPM_Index

Residuals Statistics[a]

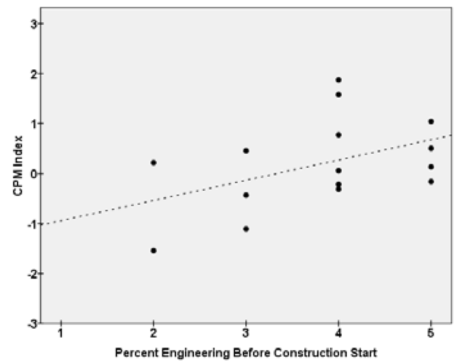
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-1.2528	.8439	.0052	.54138	15
Residual	-1.68798	1.72816	.00000	.90642	15
Std. Predicted Value	-2.324	1.549	.000	1.000	15
Std. Residual	-1.794	1.837	.000	.964	15

a. Dependent Variable: CPM_Index

- **Simple regression of CPM index and *Percent engineering before construction start***

Descriptive Statistics

	Mean	Std. Deviation	N
CPM_Index	.1904	.91202	15
actegconp	3.80	1.014	15



Correlations

		CPM_Index	actegconp
Pearson Correlation	CPM_Index	1.000	.450
	actegconp	.450	1.000
Sig. (1-tailed)	CPM_Index	.	.046
	actegconp	.046	.
N	CPM_Index	15	15
	actegconp	15	15

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.450[a]	.202	.141	.84525	.202	3.299	1	13	.092	2.306

a. Predictors: (Constant), actegconp

b. Dependent Variable: CPM_Index

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.357	1	2.357	3.299	.092[a]
	Residual	9.288	13	.714		
	Total	11.645	14			

a. Predictors: (Constant), actegconp

b. Dependent Variable: CPM_Index

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-1.347	.874		-1.541	.147		
	actegconp	.405	.223	.450	1.816	.092	1.000	1.000

a. Dependent Variable: CPM_Index

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-.5379	.6759	.1904	.41032	15
Residual	-1.00508	1.60190	.00000	.81450	15
Std. Predicted Value	-1.775	1.183	.000	1.000	15
Std. Residual	-1.189	1.895	.000	.964	15

a. Dependent Variable: CPM_Index

E.5.4 Approach 3: Rank Relative Impact of Factors by Using EFA and Multiple Regression (Refer to Section 7.5.4)

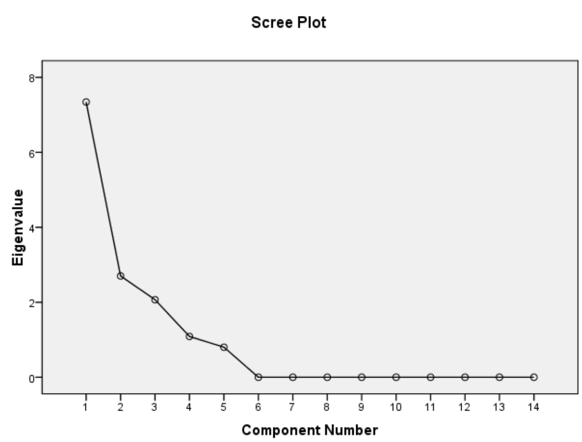
a) Step 1: EFA

Correlation Matrix

Factors	weconp	laskconp	laavconp	maavconp	sitcoconp	cplxconp	regsconp	expeconp	turnconp	supeconp	overconp	upovconp	plnegconp	actegconp
weconp	1.000	.559	.548	.632	-.158	.400	.158	.542	.447	.581	.632	.791	.542	.400
laskconp	.559	1.000	.956	.883	.442	.349	.221	.644	.781	.899	.221	.442	.644	.559
laavconp	.548	.956	1.000	.866	.433	.548	.433	.594	.816	.910	.000	.433	.594	.548
maavconp	.632	.883	.866	1.000	.500	.632	.250	.857	.707	.919	.250	.500	.857	.632
sitcoconp	-.158	.442	.433	.500	1.000	.316	-.250	.686	.707	.263	-.250	.250	.171	-.158
cplxconp	.400	.349	.548	.632	.316	1.000	.632	.542	.447	.581	-.316	.316	.542	.400
regsconp	.158	.221	.433	.250	-.250	.632	1.000	-.171	.000	.525	-.500	-.250	.343	.632
expeconp	.542	.644	.594	.857	.686	.542	-.171	1.000	.728	.585	.343	.686	.647	.217
turnconp	.447	.781	.816	.707	.707	.447	.000	.728	1.000	.557	.000	.707	.243	.000
supeconp	.581	.899	.910	.919	.263	.581	.525	.585	.557	1.000	.131	.263	.856	.830
overconp	.632	.221	.000	.250	-.250	-.316	-.500	.343	.000	.131	1.000	.500	.343	.158
upovconp	.791	.442	.433	.500	.250	.316	-.250	.686	.707	.263	.500	1.000	.171	-.158
plnegconp	.542	.644	.594	.857	.171	.542	.343	.647	.243	.856	.343	.171	1.000	.868
actegconp	.400	.559	.548	.632	-.158	.400	.632	.217	.000	.830	.158	-.158	.868	1.000

Impact Factor	Initial	Extraction
weconp	1.000	1.000
laskconp	1.000	.852
laavconp	1.000	.881
maavconp	1.000	.992
sitcoconp	1.000	.981
cplxconp	1.000	.788
regsconp	1.000	.997
expeconp	1.000	.877
turnconp	1.000	.939
supeconp	1.000	.983
overconp	1.000	1.000
upovconp	1.000	.999
plnegconp	1.000	.910
actegconp	1.000	1.000

Extraction Method: Principal Component Analysis.



According to Kaiser’s rule, four components were selected.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.343	52.449	52.449	7.343	52.449	52.449	4.613	32.950	32.950
2	2.701	19.296	71.745	2.701	19.296	71.745	3.632	25.944	58.894
3	2.068	14.771	86.516	2.068	14.771	86.516	2.814	20.101	78.995
4	1.087	7.768	94.283	1.087	7.768	94.283	2.140	15.288	94.283
5	.800	5.717	100.000						
6	4.920E-16	3.514E-15	100.000						
7	1.687E-16	1.205E-15	100.000						
8	7.987E-17	5.705E-16	100.000						
9	4.048E-18	2.891E-17	100.000						
10	-5.189E-17	-3.706E-16	100.000						
11	-1.155E-16	-8.248E-16	100.000						
12	-4.168E-16	-2.977E-15	100.000						
13	-7.412E-16	-5.294E-15	100.000						
14	-1.036E-15	-7.397E-15	100.000						

Extraction Method: Principal Component Analysis.

Pattern Matrix[a]

Variables	Component			
	1	2	3	4
Weather condition	.272	-.012	.313	.904
Labor skill	.671	-.014	-.400	.185
Labor availability	.533	-.319	-.353	.259
Material availability	.723	-.048	-.376	.238
Site condition	.067	.013	-1.022	-.183
Project complexity	.162	-.720	-.105	.339
Regulatory requirement	.308	-.849	.385	-.039
Project team experience	.373	.159	-.579	.374
Project team turnover	.019	-.211	-.665	.488
Quality of field supervision	.854	-.198	-.149	.088
Amount of scheduled overtime	.349	.787	.261	.460
Amount of unplanned overtime	-.227	.042	-.152	1.008
Percent engineering before project sanction	.979	.087	-.032	-.029
Percent engineering before construction start	1.016	-.096	.267	-.221

Factors were groups into four components based upon factor loading indicated in pattern matrix as follow:

- 1st component- Availability of information and resources for execution: Percent engineering before construction start, Quality of field supervision, Material availability, Labor skill, and Labor availability
- 2nd component- Complexity of project: Project complexity, Regulatory requirement, and Amount of scheduled overtime
- 3rd component- Project team experience: Site condition, and Project team turnover
- 4th component- Unexpected conditions: Weather condition and Amount of unplanned

Component Correlation Matrix

Component	1	2	3	4
1	1.000	-.245	-.121	.387
2	-.245	1.000	.108	.046
3	-.121	.108	1.000	-.280
4	.387	.046	-.280	1.000

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

b) Step 2: Multiple regression with stepwise and listwise deletion

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Factor1	.122	23	.200*	.955	23	.369
Factor2	.284	23	.000	.837	23	.002
Factor3	.133	22	.200*	.951	22	.324
Factor4	.191	23	.029	.901	23	.026

Correlations

		CPM_Index	Factor1	Factor2	Factor3	Factor4
CPM Index	Pearson Correlation	1.000	.544*	.243	.095	.464*
	Sig. (2-tailed)		.016	.316	.699	.045
	N	21	19	19	19	19
Factor1	Pearson Correlation	.544*	1.000	.714**	.319	.680**
	Sig. (2-tailed)	.016		.000	.148	.000
	N	19	23	23	22	23
Factor2	Pearson Correlation	.243	.714**	1.000	.508*	.489*
	Sig. (2-tailed)	.316	.000		.016	.018
	N	19	23	23	22	23
Factor3	Pearson Correlation	.095	.319	.508*	1.000	.338
	Sig. (2-tailed)	.699	.148	.016		.124
	N	19	22	22	22	22
Factor4	Pearson Correlation	.464*	.680**	.489*	.338	1.000
	Sig. (2-tailed)	.045	.000	.018	.124	
	N	19	23	23	22	23

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Factor1	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: CPM_Index

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.544[a]	.296	.254	.86094	.296	7.134	1	17	.016	2.438

a. Predictors: (Constant), Factor1

b. Dependent Variable: CPM_Index

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.288	1	5.288	7.134	.016[a]
	Residual	12.601	17	.741		
	Total	17.889	18			

a. Predictors: (Constant), Factor1

b. Dependent Variable: CPM_Index

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-2.156	.807		-2.672	.016		
	Factor1	.117	.044	.544	2.671	.016	1.000	1.000

a. Dependent Variable: CPM_Index

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Factor1
1	1	1.970	1.000	.02	.02
	2	.030	8.047	.98	.98

a. Dependent Variable: CPM_Index

Appendix F: Field Productivity Survey of Project Practitioners and Analysis Results

F.1 Field Productivity Survey (Refer to Section 7.3)

Field Productivity Impact Factor Survey

1. Name:________________________________E-mail:__________________________________
2. Years of Experience working in Construction Industry:______________________________________
3. Job Title:____
4. Company:____
   Primary Type of Organization:
   ☐ Owner ☐ Contractor (Engineering) ☐ Contractor (EPC) ☐ Contractor (PC) ☐ Contractor (CM)
   ☐ Other (please specify)____
5. Do you have experience working on **ENERGY** related construction projects e.g., Oil& Gas, Pipeline, Petro-Chemical, Chemical Manufacturing, Mining and Power Generation?
   ☐ Yes, How many years? ___________ ☐ No *(if no, please skip all questions below and submit the survey)*
6. Please select the most common **PROJECT SIZE** of the **ENERGY** related projects that you have experience on during the past 10 years. For other than Owners, the project size should reflect only your scope of work. (*please check only one*):
   ☐<$5M ☐$5M to $50M ☐$50M to $250M ☐$250M to $500M ☐$500M to $1B ☐ >$1B
7. Please indicate the **NATURE** of the **ENERGY** related projects you have mainly worked on during the past 10 years. (*please select only one*):
   ☐ Grassroots ☐ Renovation, Modernization ☐ Facility expansion; Addition
8. From your experience on the **ENERGY** related projects as specified above, please **RATE the DEGREE** to which each factor listed below **influences or impacts the Field Productivity**.

Example:

Factor	Degree Impact Field Productivity									
	No Impact				Medium Impact					Substantial Impact
1.1 A	1	2	3	4	5	6	7	8	9	10

Project Characteristics Factors	To what degree do these factors influence Field Productivity?									
	No Influence				Medium Influence					Substantial Influence
1.1 Project Size ($)	1	2	3	4	5	6	7	8	9	10
1.2 Project Nature (grassroots, addition etc)	1	2	3	4	5	6	7	8	9	10
1.3 Project Driver (cost, schedule, etc)	1	2	3	4	5	6	7	8	9	10
1.4 Site Location (urban or remote area)	1	2	3	4	5	6	7	8	9	10
1.5 Project Complexity	1	2	3	4	5	6	7	8	9	10
1.6 Contract type (fixed price, cost reimbursable, etc.)	1	2	3	4	5	6	7	8	9	10
1.7 Site Congestion	1	2	3	4	5	6	7	8	9	10

Project Execution Factors	To what degree do these execution factors impact Field Productivity?									
	No Impact				Medium Impact					Substantial Impact
2.1 Engineering Quality	1	2	3	4	5	6	7	8	9	10
2.2 Offshore Engineering	1	2	3	4	5	6	7	8	9	10
2.3 Prefabrication / Modularization	1	2	3	4	5	6	7	8	9	10
2.4 Union Workforce	1	2	3	4	5	6	7	8	9	10
2.5 Scheduled Overtime	1	2	3	4	5	6	7	8	9	10
2.6 Work Schedule (number of days in-out)	1	2	3	4	5	6	7	8	9	10
2.7 Worker Accommodations (live in camp, LOA etc.)	1	2	3	4	5	6	7	8	9	10
2.8 Mode of Travel to Worksite (bus, plane, etc.)	1	2	3	4	5	6	7	8	9	10

Project Organization & Mgmt. Factors	To what degree do these management factors impact Field Productivity?									
	No Impact				Medium Impact					Substantial Impact
3.1 Front End Planning	1	2	3	4	5	6	7	8	9	10
3.2 Workface Planning	1	2	3	4	5	6	7	8	9	10
3.3 Availability of Information	1	2	3	4	5	6	7	8	9	10
3.4 Amount of Subcontracted Work	1	2	3	4	5	6	7	8	9	10
3.5 Constructability	1	2	3	4	5	6	7	8	9	10
3.6 Material Availability	1	2	3	4	5	6	7	8	9	10
3.7 System Automation & Integration	1	2	3	4	5	6	7	8	9	10
3.8 Number of Changes	1	2	3	4	5	6	7	8	9	10
3.9 Safety Program	1	2	3	4	5	6	7	8	9	10
3.10 Planning for Startup	1	2	3	4	5	6	7	8	9	10

Human Factors	To what degree do these human factors impact Field Productivity?									
	No Impact				Medium Impact					Substantial Impact
4.1 Management Competence	1	2	3	4	5	6	7	8	9	10
4.2 Supervisor Competence	1	2	3	4	5	6	7	8	9	10
4.3 Crew Turnover Rate	1	2	3	4	5	6	7	8	9	10
4.4 Worker Attitude	1	2	3	4	5	6	7	8	9	10
4.5 Project Team Experience	1	2	3	4	5	6	7	8	9	10
4.6 Labor Availability	1	2	3	4	5	6	7	8	9	10
4.7 Labor Skill	1	2	3	4	5	6	7	8	9	10

Other Factors	To what degree do these other factors impact Field Productivity?									
	No Impact				Medium Impact					Substantial Impact
5.1 Weather Conditions	1	2	3	4	5	6	7	8	9	10
5.2 Public Regulation	1	2	3	4	5	6	7	8	9	10
Additional significant factors not listed above?										
5.3	1	2	3	4	5	6	7	8	9	10
5.4	1	2	3	4	5	6	7	8	9	10

Overall

9. Please allocate a combined **100%** to the **FIVE main categories** below. Use **the highest %** for the factor that you consider to have the **greatest influence or impact** on the Field Productivity of construction projects.

1) Project Characteristics : __________%
2) Project Execution : __________%
3) Project Organization & Mgmt: __________%
4) Human Factors : __________%
5) Other Factors : __________%

Thank you very much for your participation!

F.2 Descriptive Statistics of Survey of Project Practitioners

This section provides more detail of the data collection and an analysis of an indication of major factors affecting field productivity as mentioned in Section 7.2. The survey as shown in Appendix G was created as a web-based survey and launched to industry experts with experience working on EMR construction projects from June to September 2008. A total number of responses was 125, consisting of 72 from the U.S. and 53 from Alberta industry professionals. Due to the focus of this study, only the responses of industry experts who experienced working on large EMR projects with a project cost greater than $5M were included. The final number of responses for the analysis was 67, consisting of 26 responses from the U.S. and 41 from Alberta industry experts.

Figure F.1 and F.2 provide a distribution of number of experts' responses break down by size of projects and project nature associated with industry experts' experience. The descriptive statistics show that in general, the responses from this survey were equally distributed on every project type. The majority of Alberta respondents have experience in large project size, greater than $1B, and grassroots projects, while the U.S. respondents have experience in $5 to $50M in project value and grassroots.

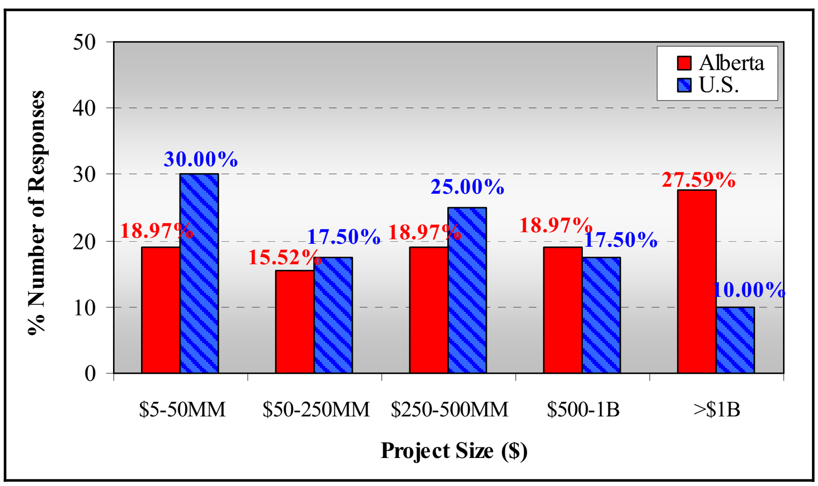


Figure F.1 Percent of Respondents' Experience by Project Size

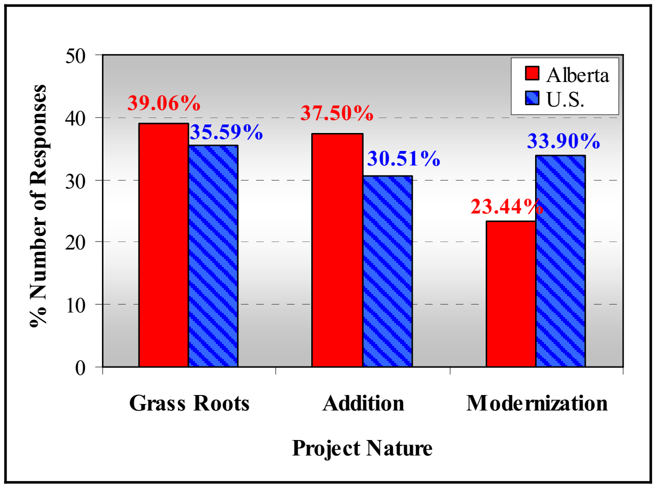


Figure F.2 Percent of Respondents' Experience on Project Nature

F.3 Differences in Perspective between U.S. Owner and Contractor Industry Experts on a Degree of Impact of Each Factor on Field Productivity

The purpose of this analysis was to determine if there were any statistically differences in perspective between U.S. owner and contractor's responses on degree of impact of each factor on field productivity. T-test was conducted on all 33 factors to identify the differences between U.S. owners' and contractors' responses. Prior to conducting *t*-test procedures, the data was examined to ensure that the *t*-test assumptions are considered plausible. Assumption 1 (independency of each observation) was acceptable since all participants were random from different companies. Assumption 2, normality on variables in each group, was met; however, some factors were violated. All factors were tested by Shapiro-Wilks test along with Skewness and Kurtosis statistic. Nonetheless, the data were not seriously nonnormally distributed and not demonstrating platykurtosis ($-3 \leq$ Kurtosis$\leq +3$) for all factors. So, *t*-tests results were acceptably robust and we can move on the next step. Assumption 3, Homogeneity of error variance, was met, except for the quality of engineering, scheduled overtime, and number of changes. As shown in Table F.1, Levene's Test supported an assumption that error variance was equal across group on every factors with $p>0.05$, except for those three aforementioned factors.

The results of *t*-test indicated no significant mean differences on every factor ($p>0.05$). As such, there is no significant difference among U.S. owners and contractors on the degree of impact of each factor on field productivity. Hence, it is appropriate for this research to combine owners and contractor responses for further analysis.

CODEBOOK

Variables	Descriptions
C_complex	Project Complexity
C_congest	Site Congestion
C_contract	Contract Type (fixed price, cost reimbursable, etc.)
C_dri	Project Driver (cost, schedule, etc)
C_loc	Site Location (urban or remote area)
C_nature	Project Nature (grassroots, addition etc)
C_size	Project Size ($)
E_engq	Engineering Quality
E_offshore	Offshore Engineering
E_prefab	Prefabrication/Modularization
E_sch_ot	Scheduled Overtime
E_travel	Mode of Travel to Worksite (bus, plane, etc.)
E_union	Union Workforce
E_work_acc	Worker Accommodations (live in camp, LOA etc.)
E_worksch	Work Schedule (# of days in-out)
H_laborav	Labor Availability
H_labsk	Labor Skill
H_mgmtcp	Management Competence
H_supcp	Supervisor Competence
H_teamexp	Project Team Experience
H_turn	Crew Turnover Rate
H_workatt	Worker Attitude
M_avinfo	Availability of Information
M_const	Constructability
M_fep	Front End Planning
M_matav	Material Availability
M_nochg	Number of Changes
M_plnstu	Planning for Startup
M_safety	Safety Program
M_sub	Amount of Subcontracted Work
M_sysauto	System Automation & Integration
M_wfp	Workface Planning
O_pubreg	Public Regulation
O_wea	Weather Conditions

Table F.1 Results of *t*-test for U.S. Owner and Contractors Perceptions

Impact Factors	Levene's Test		t-test for Equality of Means					95% CI	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Upper	Lower
C_size	3.337	0.080	-0.789	25	0.437	-0.612	0.775	-2.208	0.985
C_nature	2.969	0.097	0.106	25	0.917	0.079	0.747	-1.460	1.618
C_dri	0.385	0.541	0.028	25	0.978	0.020	0.698	-1.419	1.458
C_loc	0.307	0.585	-0.161	25	0.873	-0.112	0.693	-1.539	1.315
C_complex	0.991	0.329	-0.026	25	0.980	-0.013	0.514	-1.072	1.045
C_contract	2.826	0.105	0.568	25	0.575	0.526	0.926	-1.381	2.434
C_congest	1.441	0.241	0.219	25	0.829	0.099	0.451	-0.830	1.027
E_engq	4.666	0.041	-1.915	8	0.090	-1.309	0.684	-2.873	0.255
E_offshore	1.364	0.254	0.171	25	0.865	0.171	0.998	-1.884	2.226
E_prefab	0.991	0.329	-0.947	25	0.353	-0.487	0.514	-1.545	0.572
E_union	0.007	0.934	-0.211	25	0.835	-0.151	0.718	-1.631	1.328
E_sch_ot	4.330	0.048	0.466	25	0.645	0.164	0.353	-0.563	0.891
E_worksch	0.170	0.683	-1.031	25	0.313	-0.546	0.530	-1.637	0.545
E_work_acc	0.014	0.906	-1.184	25	0.248	-0.862	0.728	-2.361	0.637
E_travel	2.194	0.151	0.146	25	0.885	0.092	0.631	-1.207	1.392
M_fep	0.037	0.848	-0.697	25	0.492	-0.664	0.954	-2.629	1.300
M_wfp	0.649	0.428	0.505	25	0.618	0.303	0.599	-0.930	1.536
M_avinfo	0.356	0.556	-0.497	25	0.623	-0.336	0.675	-1.725	1.054
M_sub	1.053	0.315	0.647	25	0.523	0.566	0.874	-1.235	2.367
M_const	0.059	0.810	0.109	25	0.914	0.072	0.663	-1.293	1.437
M_matav	0.086	0.772	0.188	25	0.852	0.099	0.524	-0.980	1.177
M_sysauto	0.313	0.581	-1.326	25	0.197	-0.776	0.585	-1.982	0.429
M_nochg	11.251	0.003	-1.634	9	0.138	-0.796	0.487	-1.903	0.311
M_plnstu	0.738	0.398	-0.720	25	0.478	-0.671	0.932	-2.590	1.248
H_mgmtcp	0.771	0.388	-0.347	25	0.731	-0.171	0.492	-1.185	0.843
H_supcp	1.397	0.248	-0.325	25	0.748	-0.125	0.385	-0.918	0.668
H_turn	3.958	0.058	0.795	25	0.434	0.296	0.372	-0.471	1.063
H_workatt	0.832	0.371	1.213	25	0.237	0.493	0.407	-0.344	1.331
H_teamexp	0.052	0.821	0.645	25	0.525	0.513	0.796	-1.126	2.153
H_laborav	0.863	0.362	1.567	25	0.130	0.618	0.395	-0.194	1.431
H_labsk	0.509	0.482	0.257	25	0.799	0.092	0.358	-0.645	0.829
O_wea	1.512	0.230	-1.422	25	0.167	-0.711	0.500	-1.740	0.319
O_pubreg	1.218	0.280	0.644	25	0.525	0.520	0.807	-1.142	2.182

Note- Levene's test: Ho: The error variance of variable is equal
- T-test: Ho: Mean of responses on each factor between owners and contractors are equal.

F.4 Different in Perspective between Alberta Owner and Contractor Industry Experts on a Degree of Impact of Each Factor on Field Productivity

T-test was conducted on responses from Alberta experts on all 38 factors to determine if there were any statistically differences in perspective between Alberta owner's and contractor's responses on the degree of impact of each factor on field productivity. The data was examined to ensure that the *t*-test assumptions are considered plausible. Assumption 1 was met since all participants were random from different companies. Assumption 2, most of the factors was violated. They were tested by Shapiro-Wilks test along with Skewness and Kurtosis statistic. Nonetheless, the data were not seriously nonnormally distributed and not demonstrating platykurtosis ($-3 \leq$ Kurtosis$\leq +3$) for all factors. So, *t*-tests results were acceptably robust and we can move on the next step. Assumption 3, as shown in Table F.2, Levene's Test supported assumption that error variance was equal across group on every factors with $p>0.05$, except for scheduled overtime, worker accommodation, work attitude, labor skill.

The results of the *t*-test as shown in Table F.2 indicated that there are no significant mean differences on 28 factors from the total of 33 factors ($p>0.05$). This indicated that there is no significant difference among Alberta owners and contractors on the degree of impact of each of 28 factors on field productivity. However, there are 5 factors, which are *scheduled overtime*, *work accommodation*, *mode of travel*, *number of subcontractor*, and *labor availability*, that the results indicated a statistical difference in perceptions between Alberta owners and contractors. These are considered as minimal proportion, and as such, it is appropriate for this research to combine owners and contractor responses for analysis.

Table F.2 Results of t-test for Alberta Owner and Contractor's Perceptions

Variables	Levene's Test F	Levene's Test Sig.	t-test for Equality of Means t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference Upper	95% CI of the Difference Lower
C_size	1.578	0.216	-1.048	44	0.300	-0.732	0.699	-2.140	0.676
C_nature	0.485	0.490	0.080	44	0.937	0.054	0.674	-1.304	1.411
C_dri	1.271	0.266	-0.667	44	0.508	-0.451	0.676	-1.814	0.912
C_loc	0.881	0.353	-1.412	44	0.165	-0.942	0.667	-2.286	0.402
C_complex	2.605	0.114	-0.617	44	0.540	-0.366	0.593	-1.562	0.829
C_contract	0.120	0.730	-0.141	44	0.888	-0.121	0.854	-1.842	1.601
C_congest	1.096	0.301	-0.068	44	0.946	-0.045	0.652	-1.358	1.269
E_engq	0.086	0.771	-0.660	44	0.513	-0.406	0.615	-1.646	0.834
E_offshore	0.109	0.743	-0.120	44	0.905	-0.116	0.966	-2.063	1.831
E_prefab	1.170	0.285	-1.393	44	0.171	-0.897	0.644	-2.196	0.401
E_union	0.686	0.412	-1.056	44	0.297	-0.821	0.778	-2.390	0.747
E_sch_ot*	4.090	0.049	-3.804	42	0.000	-1.688	0.444	-2.583	-0.792
E_worksch	1.610	0.211	-1.203	44	0.235	-0.830	0.690	-2.221	0.560
E_work_acc*	4.524	0.039	-2.372	42	0.022	-1.317	0.555	-2.438	-0.196
E_travel	0.356	0.554	-2.275	44	0.028	-1.567	0.689	-2.955	-0.179
M_fep	3.362	0.073	-0.725	44	0.472	-0.487	0.671	-1.839	0.866
M_wfp	0.067	0.797	0.422	44	0.675	0.254	0.603	-0.961	1.470
M_avinfo	1.062	0.308	-1.046	44	0.301	-0.625	0.598	-1.829	0.579
M_sub	0.203	0.655	-2.081	44	0.043	-1.545	0.742	-3.041	-0.049
M_const	0.563	0.457	0.054	44	0.957	0.031	0.579	-1.135	1.197
M_matav	1.524	0.224	-0.165	44	0.869	-0.103	0.621	-1.355	1.149
M_sysauto	0.282	0.598	0.390	44	0.698	0.299	0.767	-1.246	1.844
M_nochg	0.410	0.525	-0.969	44	0.338	-0.598	0.617	-1.842	0.646
M_plnstu	0.370	0.546	-0.135	44	0.893	-0.107	0.793	-1.706	1.492
H_mgmtcp	0.001	0.979	-0.288	44	0.775	-0.125	0.435	-1.001	0.751
H_supcp	0.000	0.998	-1.158	44	0.253	-0.348	0.301	-0.954	0.258
H_turn	1.041	0.313	-1.009	44	0.319	-0.317	0.314	-0.950	0.316
H_workatt	4.265	0.045	-1.478	38	0.148	-0.545	0.369	-1.291	0.201
H_teamexp	2.240	0.142	-1.852	44	0.071	-0.808	0.436	-1.687	0.071
H_laborav	2.861	0.098	-2.381	44	0.022	-1.232	0.517	-2.275	-0.189
H_labsk	8.458	0.006	-1.291	41	0.204	-0.473	0.367	-1.214	0.267
O_wea	0.599	0.443	-0.931	44	0.357	-0.616	0.662	-1.950	0.718
O_pubreg	0.897	0.349	-1.221	44	0.229	-0.920	0.753	-2.438	0.598

Note: Shaded cells indicate statistical significant mean difference at $\alpha = 0.05$.

F.5 Difference in Perspective between Alberta and U.S. Industry Experts on a Degree of Impact of Each Factor on Field Productivity

T-test was performed on responses from Alberta and U.S. experts on all 33 factors to test the hypothesis that there were any statistical differences in perspective between Alberta and U.S. industry experts on a degree of impact of each factor on field productivity. The descriptive statistics of the degree impact of each factor by group are as shown in Table F.3. The data was also examined to ensure that the *t*-test assumptions were considered plausible. Assumption 1 was met since all participants from both regions were random from different companies. Assumption 2, most of the factors was violated. They were tested by Shapiro-Wilks test along with Skewness and Kurtosis statistic. Nonetheless, the data were not seriously nonnormally distributed and not demonstrating platykurtosis ($-3 \leq$ Kurtosis$\leq +3$) for all factors. So, *t*-tests results were acceptably robust and we can move on the next step. The results of the *t*-test as shown in Table F.4 indicated no significant mean differences on 31 factors with $p>0.05$. This means that there is no significant difference between Alberta and U.S. industry experts' opinion on the degree of impact of each of 31 factors on field productivity. However, there are 2 factors, which are *number of changes* and *labor skill*, that the results indicated a statistical difference in perceptions between these two regions.

Table F.3 Descriptive Statistics of Degree Impact of Each Factors from the Survey of Project Practioners

Factors	Group	N	Mean	S.D.	S.E. Mean
C_size	Alberta	27	6.56	1.826	0.351
	U.S.	46	7.35	2.183	0.322
C_nature	Alberta	27	7.44	1.739	0.335
	U.S.	46	7.11	2.079	0.306
C_dri	Alberta	27	7.11	1.625	0.313
	U.S.	46	7.04	2.097	0.309
C_loc	Alberta	27	7.70	1.613	0.310
	U.S.	46	7.13	2.104	0.310
C_complex	Alberta	27	8.26	1.196	0.230
	U.S.	46	7.67	1.839	0.271
C_contract	Alberta	27	5.63	2.169	0.417
	U.S.	46	6.63	2.636	0.389
C_congest	Alberta	27	8.56	1.050	0.202
	U.S.	46	8.33	2.012	0.297

Factors	Group	N	Mean	S.D.	S.E. Mean
M_sub	Alberta	27	5.85	2.051	0.395
	U.S.	46	5.28	2.401	0.354
M_const	Alberta	27	8.07	1.542	0.297
	U.S.	46	7.52	1.786	0.263
M_matav	Alberta	27	8.56	1.219	0.235
	U.S.	46	8.50	1.918	0.283
M_sysauto	Alberta	27	6.30	1.409	0.271
	U.S.	46	6.07	2.370	0.349
M_nochg	Alberta	27	9.19	0.962	0.185
	U.S.	46	8.37	1.925	0.284
M_plnstu	Alberta	27	7.22	2.190	0.421
	U.S.	46	6.78	2.449	0.361
H_mgmtcp	Alberta	27	8.37	1.149	0.221
	U.S.	46	8.41	1.343	0.198

Factors	Group	N	Mean	S.D.	S.E. Mean
E_engq	Alberta	27	8.30	1.353	0.260
	U.S.	46	8.22	1.908	0.281
E_offshore	Alberta	27	5.63	2.323	0.447
	U.S.	46	4.85	2.981	0.440
E_prefab	Alberta	27	7.59	1.217	0.234
	U.S.	46	7.30	2.032	0.300
E_union	Alberta	27	6.48	1.673	0.322
	U.S.	46	6.00	2.431	0.358
E_sch_ot	Alberta	27	7.26	1.130	0.217
	U.S.	46	6.83	1.889	0.279
E_worksch	Alberta	27	7.26	1.259	0.242
	U.S.	46	7.07	2.164	0.319
E_work_acc	Alberta	27	6.48	1.740	0.335
	U.S.	46	6.87	2.227	0.328
E_travel	Alberta	27	6.19	1.469	0.283
	U.S.	46	6.20	2.247	0.331
M_fep	Alberta	27	7.59	2.241	0.431
	U.S.	46	7.80	2.083	0.307
M_wfp	Alberta	27	8.04	1.400	0.269
	U.S.	46	7.89	1.865	0.275
M_avinfo	Alberta	27	8.11	1.577	0.304
	U.S.	46	8.07	1.867	0.275

Factors	Group	N	Mean	S.D.	S.E. Mean
H_supcp	Alberta	27	8.96	0.898	0.173
	U.S.	46	9.04	0.942	0.139
H_turn	Alberta	27	8.67	0.877	0.169
	U.S.	46	8.57	0.981	0.145
H_workatt	Alberta	27	8.78	0.974	0.187
	U.S.	46	8.48	1.378	0.203
H_teamexp	Alberta	27	7.89	1.867	0.359
	U.S.	46	8.15	1.398	0.206
H_laborav	Alberta	27	8.81	0.962	0.185
	U.S.	46	8.50	1.696	0.250
H_labsk	Alberta	27	9.19	0.834	0.160
	U.S.	46	8.46	1.410	0.208
O_wea	Alberta	27	8.00	1.209	0.233
	U.S.	46	7.50	2.063	0.304
O_pubreg	Alberta	27	6.26	1.893	0.364
	U.S.	46	5.72	2.363	0.348
S_ProjCha	Alberta	27	16.67	7.721	1.486
	U.S.	45	14.80	8.636	1.287
S_ProjExec	Alberta	27	23.15	10.110	1.946
	U.S.	45	23.38	12.283	1.831
S_ProjOrg	Alberta	27	27.04	10.585	2.037
	U.S.	45	25.51	11.167	1.665
S_Human	Alberta	27	25.37	11.513	2.216
	U.S.	45	23.78	15.454	2.304
S_OtherFac	Alberta	27	7.04	3.985	0.767
	U.S.	45	5.87	4.832	0.720

Table F.4 Results of t-test for U.S. Owner and Contractors Perceptions

Factors		Levene's Test		t-test for Equality of Means					95% CI of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Upper	Lower
C_size	Equal variances assumed	0.496	0.484	-1.587	71	0.117	-0.792	0.499	-1.788	0.203
	Equal variances not assumed			-1.663	62.510	0.101	-0.792	0.476	-1.745	0.160
C_nature	Equal variances assumed	0.944	0.334	0.706	71	0.482	0.336	0.476	-0.612	1.284
	Equal variances not assumed			0.740	62.490	0.462	0.336	0.454	-0.571	1.243
C_dri	Equal variances assumed	0.356	0.553	0.144	71	0.886	0.068	0.470	-0.869	1.004
	Equal variances not assumed			0.154	65.507	0.878	0.068	0.440	-0.811	0.946
C_loc	Equal variances assumed	2.201	0.142	1.220	71	0.227	0.573	0.470	-0.364	1.510
	Equal variances not assumed			1.306	65.897	0.196	0.573	0.439	-0.303	1.449

Factors		Levene's Test F	Levene's Test Sig.	t-test for Equality of Means t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference Upper	95% CI of the Difference Lower
C_complex	Equal variances assumed	1.428	0.236	1.479	71	0.144	0.585	0.396	-0.204	1.375
	Equal variances not assumed			1.646	70.161	0.104	0.585	0.356	-0.124	1.295
C_contract	Equal variances assumed	1.048	0.309	-1.668	71	0.100	-1.001	0.600	-2.197	0.196
	Equal variances not assumed			-1.755	63.190	0.084	-1.001	0.570	-2.140	0.139
C_congest	Equal variances assumed	3.748	0.057	0.549	71	0.584	0.229	0.418	-0.603	1.062
	Equal variances not assumed			0.639	70.268	0.525	0.229	0.359	-0.486	0.945
E_engq	Equal variances assumed	0.893	0.348	0.189	71	0.851	0.079	0.418	-0.755	0.913
	Equal variances not assumed			0.206	68.322	0.838	0.079	0.383	-0.686	0.844
E_offshore	Equal variances assumed	3.158	0.080	1.169	71	0.246	0.782	0.669	-0.552	2.115
	Equal variances not assumed			1.247	65.306	0.217	0.782	0.627	-0.470	2.034
E_prefab	Equal variances assumed	2.146	0.147	0.669	71	0.506	0.288	0.431	-0.571	1.147
	Equal variances not assumed			0.758	70.946	0.451	0.288	0.380	-0.470	1.046
E_union	Equal variances assumed	2.512	0.117	0.909	71	0.366	0.481	0.530	-0.574	1.537
	Equal variances not assumed			0.999	69.085	0.321	0.481	0.482	-0.480	1.443
E_sch OT	Equal variances assumed	4.877	0.030	1.081	71	0.283	0.433	0.401	-0.365	1.232
	Equal variances not assumed			1.226	70.953	0.224	0.433	0.353	-0.271	1.138
E_worksch	Equal variances assumed	3.657	0.060	0.425	71	0.672	0.194	0.457	-0.717	1.105
	Equal variances not assumed			0.484	71.000	0.630	0.194	0.401	-0.605	0.993
E_work_acc	Equal variances assumed	1.014	0.317	-0.776	71	0.440	-0.388	0.500	-1.385	0.609
	Equal variances not assumed			-0.827	65.203	0.411	-0.388	0.469	-1.325	0.549
E_travel	Equal variances assumed	5.944	0.017	-0.022	71	0.983	-0.010	0.484	-0.976	0.955
	Equal variances not assumed			-0.024	70.087	0.981	-0.010	0.435	-0.879	0.858
M_fep	Equal variances assumed	0.647	0.424	-0.408	71	0.685	-0.212	0.519	-1.247	0.824
	Equal variances not assumed			-0.400	51.424	0.691	-0.212	0.529	-1.274	0.851
M_wfp	Equal variances assumed	0.841	0.362	0.352	71	0.726	0.146	0.414	-0.681	0.972
	Equal variances not assumed			0.379	66.607	0.706	0.146	0.385	-0.623	0.914
M_avinfo	Equal variances assumed	0.002	0.966	0.107	71	0.915	0.046	0.428	-0.808	0.900
	Equal variances not assumed			0.112	62.086	0.911	0.046	0.410	-0.773	0.865
M_sub	Equal variances assumed	1.536	0.219	1.030	71	0.306	0.569	0.552	-0.532	1.671
	Equal variances not assumed			1.074	61.602	0.287	0.569	0.530	-0.491	1.629
M_const	Equal variances assumed	0.649	0.423	1.340	71	0.185	0.552	0.412	-0.270	1.374
	Equal variances not assumed			1.392	61.137	0.169	0.552	0.397	-0.241	1.346
M_matav	Equal variances assumed	2.092	0.152	0.135	71	0.893	0.056	0.411	-0.764	0.875
	Equal variances not assumed			0.151	70.472	0.880	0.056	0.367	-0.677	0.788

Factors		Levene's Test F	Levene's Test Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference Upper	95% CI of the Difference Lower
M_sysauto	Equal variances assumed	3.520	0.065	0.460	71	0.647	0.231	0.502	-0.770	1.232
	Equal variances not assumed			0.522	70.971	0.603	0.231	0.442	-0.651	1.113
M_nochg	Equal variances assumed	3.797	0.055	2.052	71	0.044	0.816	0.397	0.023	1.608
	Equal variances not assumed			2.407	69.631	0.019	0.816	0.339	0.140	1.492
M_plnstu	Equal variances assumed	0.702	0.405	0.769	71	0.444	0.440	0.571	-0.700	1.579
	Equal variances not assumed			0.792	59.618	0.431	0.440	0.555	-0.671	1.550
H_mgmtcp	Equal variances assumed	0.304	0.583	-0.138	71	0.891	-0.043	0.309	-0.659	0.574
	Equal variances not assumed			-0.144	61.565	0.886	-0.043	0.297	-0.636	0.551
H_supcp	Equal variances assumed	0.161	0.689	-0.359	71	0.721	-0.081	0.224	-0.528	0.367
	Equal variances not assumed			-0.363	56.747	0.718	-0.081	0.222	-0.524	0.363
H_turn	Equal variances assumed	0.960	0.331	0.443	71	0.659	0.101	0.229	-0.355	0.558
	Equal variances not assumed			0.456	59.627	0.650	0.101	0.222	-0.343	0.546
H_workatt	Equal variances assumed	3.968	0.050	0.992	71	0.325	0.300	0.302	-0.303	0.902
	Equal variances not assumed			1.083	68.421	0.282	0.300	0.276	-0.252	0.851
H_teamexp	Equal variances assumed	0.000	0.992	-0.685	71	0.496	-0.263	0.385	-1.030	0.503
	Equal variances not assumed			-0.636	43.215	0.528	-0.263	0.414	-1.099	0.572
H_labor ava	Equal variances assumed	5.568	0.021	0.883	71	0.380	0.315	0.357	-0.396	1.026
	Equal variances not assumed			1.012	70.955	0.315	0.315	0.311	-0.306	0.935
H_labsk	Equal variances assumed	10.17	0.002	2.443	71	0.017	0.729	0.298	0.134	1.323
	Equal variances not assumed			2.775	70.984	0.007	0.729	0.263	0.205	1.252
O_wea	Equal variances assumed	3.851	0.054	1.147	71	0.255	0.500	0.436	-0.369	1.369
	Equal variances not assumed			1.306	70.997	0.196	0.500	0.383	-0.264	1.264
O_pubreg	Equal variances assumed	1.348	0.250	1.015	71	0.314	0.542	0.534	-0.523	1.607
	Equal variances not assumed			1.075	64.255	0.286	0.542	0.504	-0.465	1.549

Note: Shaded cells indicate statistical significant mean difference at α = 0.05.

F.6 Ranking Order of Factors Impacting Field Productivity by Regions

By calculating the relative impact of factor, the productivity factors were ranked as shown in Table F.5. The relative impact of factor is calculated by the sum of the ratings given to each factor by the respondents (the rate of 1 to 5 in this study), divided by the total highest degree (number of respondents-*N* multiplied by 5). The higher relative impact scores indicate a relatively higher degree of impact of that factor compared to others. As a result, the rank order was assigned to 33 factors according to their relative impact scores.

Table F.5 Ranking Order of Factors Impacting Field Productivity by Regions

Factors	Sum Degree Impact			Relative Impact			Rank		
	U.S.	Alberta	All	U.S. (N=26)	Alberta (N=41)	All (N=67)	Alberta	U.S.	All
Sum of H_supcp	233	369	602	0.896	0.900	0.899	**1**	**3**	**1**
Sum of M_matav	222	361	583	0.854	0.880	0.870	**2**	**8**	**4**
Sum of H_turn	224	352	576	0.862	0.859	0.860	**3**	**6**	**6**
Sum of H_labsk	238	351	589	0.915	0.856	0.879	**4**	**2**	**3**
Sum of C_congest	223	351	574	0.858	0.856	0.857	**5**	**7**	**8**
Sum of M_nochg	239	350	589	0.919	0.854	0.879	**6**	**1**	**2**
Sum of H_workatt	227	349	576	0.873	0.851	0.860	**7**	**5**	**5**
Sum of E_engq	215	346	561	0.827	0.844	0.837	**8**	**10**	**9**
Sum of H_laborav	229	345	574	0.881	0.841	0.857	**9**	**4**	**7**
Sum of H_mgmtcp	217	343	560	0.835	0.837	0.836	**10**	**9**	**10**
Sum of H_teamexp	205	339	544	0.788	0.827	0.812	**11**	**16**	**12**
Sum of M_avinfo	210	337	547	0.808	0.822	0.816	**12**	**12**	**11**
Sum of M_wfp	209	330	539	0.804	0.805	0.804	**13**	**14**	**13**
Sum of M_fep	197	326	523	0.758	0.795	0.781	**14**	**18**	**17**
Sum of O_wea	206	325	531	0.792	0.793	0.793	**15**	**15**	**15**
Sum of C_complex	215	319	534	0.827	0.778	0.797	**16**	**11**	**14**
Sum of M_const	210	318	528	0.808	0.776	0.788	**17**	**13**	**16**
Sum of E_prefab	197	309	506	0.758	0.754	0.755	**18**	**19**	**18**
Sum of C_size	174	307	481	0.669	0.749	0.718	**19**	**25**	**23**
Sum of C_loc	198	298	496	0.762	0.727	0.740	**21**	**17**	**19**
Sum of C_dri	187	298	485	0.719	0.727	0.724	**20**	**24**	**21**
Sum of C_nature	194	296	490	0.746	0.722	0.731	**22**	**20**	**20**
Sum of E_worksch	188	295	483	0.723	0.720	0.721	**23**	**22**	**22**
Sum of E_sch_ot	188	288	476	0.723	0.702	0.710	**24**	**23**	**24**
Sum of E_work_acc	167	288	455	0.642	0.702	0.679	**25**	**26**	**26**
Sum of M_plnstu	189	282	471	0.727	0.688	0.703	**26**	**21**	**25**
Sum of C_contract	147	268	415	0.565	0.654	0.619	**27**	**32**	**30**
Sum of M_sysauto	163	258	421	0.627	0.629	0.628	**28**	**28**	**27**
Sum of E_travel	159	256	415	0.612	0.624	0.619	**29**	**30**	**29**
Sum of E_union	165	251	416	0.635	0.612	0.621	**30**	**27**	**28**
Sum of O_pubreg	160	241	401	0.615	0.588	0.599	**31**	**29**	**31**
Sum of M_sub	152	215	367	0.585	0.524	0.548	**32**	**31**	**32**
Sum of E_offshore	147	201	348	0.565	0.490	0.519	**33**	**33**	**33**

Correlations

		Rank_U.S.	Rank_Alberta
Rank_US	Pearson Correlation	1.000	.942**
	Sig. (2-tailed)		.000
	N	33	33
Rank_Alberta	Pearson Correlation	.942**	1.000
	Sig. (2-tailed)	.000	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

As shown in Table F.5, the top five factors were determined by Alberta industry experts which are *supervisor competence*, *material availability*, *project team turnover rate*, *labor skill*, and *site congestion*. The rank of factors indicated by Alberta's experts was slightly different from that of U.S. experts due to differences in project environments. However, the factors impacting field productivity of construction productivity are common. To determine if there are differences in the ranks indicated by Alberta and U.S. experts, the Spearman's rank correlation was performed. From a correlation result below, it indicates statistically high rank correlation of 0.942 between Alberta and U.S experts.

Appendix G: Alberta Benchmarking Questionnaire (Extracted Version)

Table of Contents

1. Project General Information

Your Company Name: ____

Please provide the Name that you will use to refer to this Project: ______________

Location of Project:

City: ____

Province:____

Country:____

Contact Person: (Benchmarking Associate) __________________________

Contact's Phone: ______________________

Contact's Fax: ________________________

Contact's E-mail Address: ____

All Project costs should be recorded herein using Canadian Dollars (CAD).

Project quantities to be recorded as: ☐ Metric(cm., m., tonne) ☐ Imperial(in., ft., ton)

Expected project Completion Date (MM/DD/Year): _____________________

1.1 Project Description

Principle Type of Project:

Choose a Project Type which **best** describes the project from the categories below. If the project is a mixture of two or more of those listed, select the principle type. If the project type does not appear in the list, select other under the appropriate industry group and specify the project type.

Heavy Industrial

- ☐ Chemical Manufacturing
- ☐ Electrical (Generating)
- ☐ Environmental
- ☐ Metals Refining/Processing
- ☐ Mining
- ☐ Natural Gas Processing
- ☐ Oil Exploration/Production
- ☐ Oil Refining
- ☐ Oil Sands Mining/Extraction
- ☐ Oil Sands SAGD
- ☐ Oil Sands Upgrading
- ☐ Cogeneration
- ☐ Pulp and Paper
- ☐ Pipeline
- ☐ Gas Distribution
- ☐ Other Heavy Industrial

Light Industrial

- ☐ Automotive Manufacturing
- ☐ Consumer Products Manufacturing
- ☐ Foods
- ☐ Microelectronics Manufacturing
- ☐ Office Products Manufacturing
- ☐ Pharmaceutical Manufacturing
- ☐ Pharmaceutical Labs
- ☐ Clean Room (Hi-Tech)
- ☐ Other Light Industrial

Buildings

- ☐ Communications Center
- ☐ Courthouse
- ☐ Dormitory/Hotel/Housing/Residential
- ☐ Embassy
- ☐ Low rise Office (≤3 floors)
- ☐ High rise Office (>3 floors)
- ☐ Hospital
- ☐ Laboratory
- ☐ Maintenance Facilities
- ☐ Movie Theatre
- ☐ Parking Garage
- ☐ Physical Fitness Center
- ☐ Prison
- ☐ Restaurant/Nightclub
- ☐ Retail Building
- ☐ School
- ☐ Warehouse
- ☐ Other Buildings

Infrastructure

- ☐ Airport
- ☐ Electrical Distribution
- ☐ Flood Control
- ☐ Highway
- ☐ Marine Facilities
- ☐ Navigation
- ☐ Rail
- ☐ Tunneling
- ☐ Water/Wastewater
- ☐ Telecom, Wide Area Network
- ☐ Other Infrastructure

If other, please describe: ______________________________

1.2 Project Nature

From the list below select the category that best describes the nature of this project. If your project is a combination of these natures, select the category that you would like your project to be benchmarked against. Please see the glossary for definitions.

The Project Nature was:

- ☐ Grass Roots, Green Field
- ☐ Modernization, Renovation
- ☐ Addition, Expansion
- ☐ Other Project Nature (Please describe):

Is this project part of a larger project? ◘ **Yes** ◘ **No**

If Yes, please describe: ____________________________

1.3 Project Characteristics

a. Project Drivers

Select the primary driver influencing the execution of this project. Assume safety is a given for all projects. This section must be verified again at project closeout.

The primary driver was:

- ☐ Cost
- ☐ Schedule
- ☐ Meeting Product Specifications
- ☐ Production Capacity
- ☐ Other (Please describe):
- ☐ No primary driver

b. Turnarounds/Shutdowns/Outages

Construction performance (cost, schedule and quality) during project turnarounds, shutdowns, and outages may be impacted by schedule demands of the turnaround. These turnarounds may be scheduled or unscheduled. Please complete the blocks below to indicate the percentage of construction work completed during turnaround.

1. Percent construction during **scheduled turnaround:**		%
2. Percent construction during **unscheduled turnaround:**		%
3. Percent construction during **non-turnaround:**		%

Note: the percentages should add up to 100 %

c. Percent Modularization

Choose a percentage value that best describes the level of modularization (offsite construction) used. This value should be determined as a ratio of the cost of all modules divided by total installed cost.

◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**

d. Percent Offsite Construction Labour Hours

Choose a percentage value that best describes the level of offsite labour hours for building modules. This value should be determined as a ratio of the offsite labour hours of all modules divided by **total construction hours**.

◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**

1.4 Project Delivery System

Please choose the project delivery system from those listed below that most closely characterizes the delivery system used for your project. If more than one delivery system was used, select the primary system.

	Delivery System	Description
	Traditional Design-Bid-Build	Serial sequence of design and construction phases; Owner contracts separately with designer and constructor.
	Design-Build (or EPC)	Overlapped sequence of design and construction phase; procurement normally begins during design; owner contracts with Design-Build (or EPC) contractor.
	CM at Risk	Overlapped sequence of design and construction phases; procurement normally begins during design; owner contracts separately with designer and CM at Risk (constructor). CM holds the contracts.
	Multiple Design-Build	Overlapped sequence of design and construction phases; procurement normally begins during design; owner contracts with two Design-Build (or EPC) contractors, one for process and one for facilities.
	Parallel Primes	Overlapped sequence of design and construction phases; Procurement normally begins during design. Owner contracts separately with designer and multiple prime constructors.
	Other Delivery System_________________	

Did you use a Construction Manager not at Risk in conjunction with the selected delivery system?
Yes_________________ No_________________

1.5 Project Complexity

Choose a value that best describes the level of complexity for this project as compared to other projects from all the companies within the same industry sector. For example, if this is a heavy industrial project, how does it compare in complexity to other heavy industrial projects? Use the definitions below as general guidelines.

- **Low** - Characterized by the use of no unproven technology, small number of process steps, small facility size or process capacity, previously used facility configuration or geometry, proven construction methods, etc.
- **High**- Characterized by the use of unproven technology, an unusually large number of process steps, large facility size or process capacity, new facility configuration or geometry, new construction methods, etc.

Low			Average				High		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
1	2	3	4	5	6	7	8	9	10

1.6 Project Scope

Please provide a brief description of the project scope (what is actually being designed / constructed), limit your response to 200 words.

……

……

1.7 Project Participation

First, indicate the percentage of each **function** performed by your company.

Next, for each function at least partially performed by a contractor, indicate the **principle contract type** used. If more than one contract type was used, indicate the most prevalent.

Principle Type of Contract for each company: Unit price refers to a price for in place units of work and does not refer to hourly charges for skill categories or time card mark-ups. Hourly rate payment schedules should be categorized as cost reimbursable. The contract type for your own company's contribution should be recorded as In House.

- Cost Reimbursable/Target Price
- Guaranteed Maximum Price
- Lump Sum
- Unit Price

Finally, indicate if **incentives** were used, if you had an **Alliance** with the contractors for each function, and whether **COAA or CII Member** companies were involved.

Contract Incentives: Please indicate whether cost, schedule, safety, and quality incentives were used. Incentives may be positive (a financial incentive for attaining an objective), negative (a financial disincentive for failure to achieve an objective), or both. Indicate "none" if no incentives were used for a category.

Alliance Use: Was the participating company an Alliance Partner? An alliance partner is a company with whom your company has a long-term formal strategic agreement that ordinarily covers multiple projects.

COAA or CII Member: Was the company that involved this function a COAA or CII Member?

Functions	Owner Response Table				
	Your Company Self Perform (0-100%)	**Principle Contract Type** (select one per phase)	**Contractor Incentive Use** (select one for each incentive type)	**Alliance Use**	**COAA or CII Member**
Front End Planning	%	◘ Cost Reimbursable / Target Price ◘ Guaranteed Max Price ◘ Lump Sum ◘ Unit Price	**Cost** ◘ Positive ◘ Negative ◘ Both ◘ None **Schedule** ◘ Positive ◘ Negative ◘ Both ◘ None **Safety** ◘ Positive ◘ Negative ◘ Both ◘ None **Quality** ◘ Positive ◘ Negative ◘ Both ◘ None	☐ Yes ☐ No	◘ COAA ◘ CII ◘ Both ◘ None
Detailed Engineering	%	◘ Cost Reimbursable / Target Price ◘ Guaranteed Max Price ◘ Lump Sum ◘ Unit Price	**Cost** ◘ Positive ◘ Negative ◘ Both ◘ None **Schedule** ◘ Positive ◘ Negative ◘ Both ◘ None **Safety** ◘ Positive ◘ Negative ◘ Both ◘ None **Quality** ◘ Positive ◘ Negative ◘ Both ◘ None	☐ Yes ☐ No	◘ COAA ◘ CII ◘ Both ◘ None
Procurement	%	◘ Cost Reimbursable / Target Price ◘ Guaranteed Max Price ◘ Lump Sum ◘ Unit Price	**Cost** ◘ Positive ◘ Negative ◘ Both ◘ None **Schedule** ◘ Positive ◘ Negative ◘ Both ◘ None **Safety** ◘ Positive ◘ Negative ◘ Both ◘ None **Quality** ◘ Positive ◘ Negative ◘ Both ◘ None	☐ Yes ☐ No	◘ COAA ◘ CII ◘ Both ◘ None
Construction	%	◘ Cost Reimbursable / Target Price ◘ Guaranteed Max Price ◘ Lump Sum ◘ Unit Price	**Cost** ◘ Positive ◘ Negative ◘ Both ◘ None **Schedule** ◘ Positive ◘ Negative ◘ Both ◘ None **Safety** ◘ Positive ◘ Negative ◘ Both ◘ None **Quality** ◘ Positive ◘ Negative ◘ Both ◘ None	☐ Yes ☐ No	◘ COAA ◘ CII ◘ Both ◘ None
Startup	%	◘ Cost Reimbursable / Target Price ◘ Guaranteed Max Price ◘ Lump Sum ◘ Unit Price	**Cost** ◘ Positive ◘ Negative ◘ Both ◘ None **Schedule** ◘ Positive ◘ Negative ◘ Both ◘ None **Safety** ◘ Positive ◘ Negative ◘ Both ◘ None **Quality** ◘ Positive ◘ Negative ◘ Both ◘ None	☐ Yes ☐ No	◘ COAA ◘ CII ◘ Both ◘ None

1.8 Union Workforce

Please indicate the percentage of Building Trades, Alternate Union and Non Union Labour employed for the following disciplines. Each row should sum up to 100%.

Building Trades Unions are organizations of workers formed for the purpose of advancing their members' interests in respect to wages, benefits and working conditions. Building trades unions typically represent single trades.
Example: IBEW - International Brotherhood of Electrical Workers

Alternate Unions are multicraft unions or wall-to-wall unions similar in purpose to building trades unions but are inclusive of mulitiple trades and industries.
Example: CLAC - Christian Labour Association of Canada

Discipline	Percentage Building Trades	Percentage Alternate Union	Percentage Non Union	Total (%)
Concrete	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Structural Steel	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Electrical	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Piping	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Instrumentation	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Equipment	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%
Insulation	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	____% ◘ NA ◘Unknown	100%

2. Performance

2.1 Budgeted and Actual Project Costs by Phase

Please indicate the Budgeted (Baseline) and Actual Project Costs by phase. All project costs should be recorded using Canadian Dollars (CAD).

1. Budget amounts include contingency and correspond to funding approved at time of Project Sanction. This is the original baseline budget, and should not be updated to include any changes since change data are collected in a later section. Metrics definitions specifically address changes as appropriate.
2. Click on the project phase links below for phase definitions and typical cost elements.
3. If this project did not include a particular phase, please select N/A.
4. The total project **budget** amount should include all **planned expenses (**excluding the cost of land**)** from front end planning through startup, including amounts estimated for in-house salaries, overhead, travel, etc.
5. The total **actual** project cost should include all **actual** project costs at time of project closeout **(**excluding the cost of land**)** from front end planning through startup, including amounts expended for in-house salaries, overhead, travel.
6. **If you know total project costs but have incomplete phase information**, you may enter as much phase information as you know and override the automatic totaling function by manually filling in the total project cost. As long as you don't click back into a phase field, your total will be accepted and recorded.

Project Phase		Baseline Budget (Including Contingency)	Amount of Contingency in Budget	Actual Phase Cost
Front End Planning		☐ NA ☐ Unknown	☐ NA ☐ Unknown	☐ NA ☐ Unknown
Detail Engineering		☐ NA ☐ Unknown	☐ NA ☐ Unknown	☐ NA ☐ Unknown
Procurement[1]		☐ NA ☐ Unknown	☐ NA ☐ Unknown	☐ NA ☐ Unknown
Construction[2]	Directs			
	Indirects			
	Total	☐ NA ☐ Unknown	☐ NA ☐ Unknown	☐ NA ☐ Unknown
Startup		☐ NA ☐ Unknown	☐ NA ☐ Unknown	☐ NA ☐ Unknown
Total Project				
If you track the cost of construction management, please provide it. $______________				

Remark: [1] **Procurement Phase Cost** – Costs of **Major Equipment** including process and mechanical equipment, construction equipment left on site and used after commissioning (see table p.13) and modules fabricated offsite.

[2] **Construction Cost** – See "**Instructions for Construction Direct and Indirect Costs**" below.

Construction Direct and Indirect Cost

Direct costs are those which are readily or directly attributed to, or become an identifiable part of, the final project (e.g., piping labour and material). Indirect costs are costs that cannot be attributed readily to a part of the final product (e.g. temporary facilities).

Please use the following table as a guide in categorizing direct and indirect construction cost.

Direct Construction Cost	**Indirect Construction Cost**
Direct labour - See construction productivity table (p.27)	Indirect labour - See construction productivity table
Labour burdens and fringe benefits	Overtime premium (additional cost for which no work is performed)
Direct subcontracts	Mobilization, Demobilization
Bulk materials - See bulk material table (p.12)	Construction office trailers and equipment.
	Construction utilities (power, water etc.)
	Temporary construction (e.g. roads, fencing, fab. shops, etc.)
	Construction equipment (rental/ ownership& consumerables – fuel, oil, etc.)
	Other consumables- small tools, supplies
	Scaffolding materials (rental/ ownership)
	Field services
	Permits (construction related)
	Vendor representatives
	Freight (for items listed in this table)
	Catering, accommodations
	Travel
	Misc. (insurance, etc.)
	Indirect subcontracts

Note: For benchmarking purposes exclude the following:
- Demolition cost
- Remediation cost
- Site preparation cost (construction cost begins with excavation for foundations or driving of piles)

Provide data for Construction subtotal if indirect and indirect breakout is not available.

Bulk Material

Bulk materials are generally defined as the balance of construction components outside the major equipment classification. Bulks are commonly referred to as commodity materials. In general bulks do not include tagged/numbered equipment. Please use the following table as a guide in categorizing cost of bulk materials.

Bulk Material Reference Table	
Craft	**Examples of Bulk Material**
Civil/Structural	Concrete
	Reinforcing Steel
	Concrete Embeds
	Structural Steel
	Piling
Pipe	Pipe
	Fittings
	Manual valves
	Hangers / Supports
	Process Air Duct
Instrumentation	Control valves
	Control panels
	Field instrumentation
	Instrument air tubing
Electrical	Cable tray
	Conduit
	Wire/Cable
	Light fixtures
	Electrical heat tracing
	Grounding
Misc.	Insulation
	Paint
	Fireproofing

Total Cost of Major Equipment

The purpose of this question is to determine the extent to which the overall project cost is driven by the purchase of **major equipment in general and more particularly, mechanical and process equipment.** Please see the Equipment Reference Table provided below. Record the total purchase cost of major equipment overall as well as the total purchase cost of mechanical and process equipment.

Total Cost of Major Equipment $____________________ ◘ N/A ◘ Unknown

Total Cost of Mechanical and process Equipment $__________ ◘ N/A ◘ Unknown

Equipment Reference Table	
Examples of Major Equipment	**Kinds of Equipment Covered**
Electrical Equipment	
HVAC Systems	Prefabricated air supply houses
Motors	600V and above
Electricity Generation and Transmission	Major electrical items (e.g., unit substations, transformers, switch gear, motor-control centers, batteries, battery chargers, turbines and other miscellaneous power generation equipment).
Mining Equipment	
Loaders and Haulers	Dozers, haul trucks, graders.
Excavators	Hydraulic/ electric shovels, draglines, etc.
Material Handling Equipment	
Mechanical & Process Equipment	
Exchangers	Heat transfer equipment: tubular exchangers, condensers, evaporators, reboilers, coolers (including fin-fan coolers and cooling towers).
Pumps	All types of liquid pumps and drivers.
Direct-fired Equipment	Fired heaters, furnaces, boilers, kilns, and dryers, including associated equipment such as super-heaters, air preheaters, burners, stacks, flues, draft fans and drivers, etc.
Columns and Pressure Vessels	Towers, columns, reactors, unfired pressure vessels, bulk storage spheres, and unfired kilns; includes internals such as trays and packing.
Tanks	Atmospheric storage tanks, bins, hoppers, and silos.
Vacuum Equipment	Mechanical vacuum pumps, ejectors, and other vacuum producing apparatus and integral auxiliary equipment.
Material Handling Equipment	Conveyers, cranes, hoists, chutes, feeders, scales and other weighing devices, packaging machines, and lift trucks.
Package Units	Integrated systems bought as a package (e.g., air dryers, air compressors, refrigeration systems, ion exchange systems, etc.).
Special Processing Equipment	Agitators, crushers, pulverizers, blenders, separators, cyclones, filters, centrifuges, mixers, dryers, extruders, fermenters, reactors, pulp and paper, and other such machinery with their drivers.
Include freight. Exclude costs of project team, costs for field services, bulk construction equipment (such as valves, bus duct etc.) and off-the-shelf equipment.	

2.2 Planned and Actual Project Schedule

Please indicate your company's Planned Baseline and Actual Project Schedule by phase:

1. The dates for the planned schedule should be those in effect at Project Sanction. If you cannot provide an exact day for either the planned or actual, estimate to the nearest week.
2. Click on the project phase links below for a description of starting and stopping points for each phase.
3. If this project did not include a particular phase please select N/A.
4. **If you have incomplete phase information**, you must enter overall project start and stop dates. Please enter as much phase information as possible.

Project Phase	Baseline Schedule		Actual Schedule	
	Start **mm/dd/yyyy**	Stop **mm/dd/yyyy**	Start **mm/dd/yyyy**	Stop **mm/dd/yyyy**
Front End Planning	◘Unknown	◘Unknown	◘Unknown	◘Unknown
Detail Engineering	◘Unknown	◘Unknown	◘Unknown	◘Unknown
Procurement	◘Unknown	◘Unknown	◘Unknown	◘Unknown
Construction	◘Unknown	◘Unknown	◘Unknown	◘Unknown
Startup	◘Unknown	◘Unknown	◘Unknown	◘Unknown
Overall Project Start and Stop Dates	◘Unknown	◘Unknown	◘Unknown	◘Unknown

% Design Complete

What percentage of detailed engineering work-hours was completed as of total Project Sanction? __________%

◘ Unknown

What percentage of detailed engineering work-hours was completed as of start of the construction phase? __________%

◘ Unknown

2.3 Project Development Changes and Scope Changes

Please record the **approved** changes to your project by phase in the table provided below. For each phase indicate the net cost impact, and the net schedule impact resulting from project **approved** development changes and scope changes. Either the owner or contractor may initiate changes. **All costs should be recorded using Canadian Dollars (CAD).**

Project Development Changes include those changes required to execute the original scope of work or obtain original process basis.

Scope Changes include changes in the base scope of work or process basis.

1. Changes should be included in the phase in which they were initiated. Click on the project phase links below for assistance in classifying the changes by project phase. **If you cannot provide the requested change information by phase** but can provide the information for the total project, please fill in the totals field manually, thereby overriding the totaling function. As long as you don't click back into a phase field, your total will be accepted and recorded.
2. Indicate whether the net impact was a decrease (-) or an increase (+) by indicating a negative number for a decrease and a positive number for an increase. If no change orders were granted during a phase, write "0" in that row.

Project Phase	Cost Increase (+) / Decrease (-) of Project Development Changes	Cost Increase (+) / Decrease (-) of Scope Changes	Schedule Increase (+) / Decrease (-) of Project Development Changes (weeks)	Schedule Increase (+) / Decrease (-) of Scope Changes (weeks)
Pre-Construction	$________ ◘ Unknown	$________ ◘Unknown	________ ◘Unknown	________ ◘Unknown
Construction thru Startup	$________ ◘ Unknown	$________ ◘ Unknown	________ ◘Unknown	________ ◘Unknown
Totals	$________	$________	________	________

3. Practices

3.1 Front End Planning

Front End Planning involves the process of developing sufficient strategic information that owners can address risk and decide to commit resources to maximize the chance for a successful project. Front End Planning includes putting together the project team, selecting technology, selecting project site, developing project scope, and developing project alternatives. Front End Planning is often perceived as synonymous with front-end loading, front-end planning, feasibility analysis, and conceptual planning.

Your Front End Planning score is based on your response to the questions below (4 for owners or 6 for contractors) and to selected questions from the PDRI (Project Definition Rating Index) which follows. If you use the PDRI as part of your project planning process, please respond to the following questions and then complete the PDRI (either Industrial, Building, or both) which follow. If you do not desire to use the full PDRI(s), you may obtain your Front End Planning score by completing the questions below (4 for owners or 6 for contractors) and completing only the PDRI questions that are highlighted by italics. You will obtain the same Front End Planning score that you would have received if you completed the full PDRI. Those completing the full PDRI(s) will also receive their score(s) on the 0 to 1000 scale used for PDRI assessments.

Contractor Question Only

Select the response below that best describes your company's participation in the Front End Planning effort.

Did your company participate in the Front End Planning effort?

- ◘ Yes, as the pre-project planner.
- ◘ Yes, as a consultant.
- ◘ No, my company did not participate in the preplanning effort. Please skip following Front End Planning questions and continue with the next best practice (Team Building).

Contractor Question Only

Did your company formally assess the quality of the Front End Planning effort?

Yes ◘ No ◘

Owner and Contractor Questions

Select a number below that best describes the composition of the Front End Planning team using the scale and definitions provided.

Poor			Average				Excellent		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

1. **Excellent -** Highly skilled and experienced members with authority; representation from business, project management, technical disciplines, and operations; able to respond to both business and project objectives.
2. **Poor -** Members with a poor combination of skill or experience that lack authority; insufficient representation from business, project management, technical disciplines, and operations; unable to respond to both business and project objectives.

Select a number below that best describes the technology evaluation performed for this project during Front End Planning.

Poor			Average				Excellent		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
1	2	3	4	5	6	7	8	9	10

1. **Excellent -** Thorough and detailed identification and analysis of existing and emerging technologies for feasibility and compatibility with corporate business and operations objectives. Scale-up problems and hands-on process experience were considered.
2. **Poor -** Poor or no technology evaluation.

Select a number below that best describes the evaluation of alternate siting locations.

Poor			Average				Excellent		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
1	2	3	4	5	6	7	8	9	10

1. **Excellent -** Thorough and detailed assessment of relative strengths and weaknesses of alternate locations to meet owner requirements.
2. **Poor -** Poor or no evaluation of alternate siting locations.

Select a number below that best describes the risk analysis performed for project alternatives.

Poor			Average				Excellent		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
1	2	3	4	5	6	7	8	9	10

1. **Excellent -** Risks associated with the selected project alternatives were identified and analyzed. These analyses included financial/business, regulatory, project and operational risk categories in order to minimize the impacts of risks on project success.

Poor - Poor or no risk analysis performed for project alternatives.

3.2 Project Risk Assessment

Project risk assessment is the process to identify, assess and manage risk. The project team evaluates risk exposure for potential project impact to provide focus for mitigation strategies.

Select the response below that best describes your company's participation in project risk assessment effort.

1. Was the project successful in including the appropriate parties to work through an assessment of risk posed to the project?

No		Moderately		Very	
0	1	2	3	4	NA/UNK
◘	◘	◘	◘	◘	◘

2. To what extent was an environment created to encourage free discussions of risk concerns?

Not at all		Moderately		Very	
0	1	2	3	4	NA/UNK
◘	◘	◘	◘	◘	◘

3. To what extent was a comprehensive and systematic process used to identify and assess risks posed to the project?

No Process Used		Most		Very Extensively Used	
0	1	2	3	4	NA/UNK
◘	◘	◘	◘	◘	◘

4. Were effective mitigation strategies developed for the identified risks?

Not at all		Moderate		Very Effective	
0	1	2	3	4	NA/UNK
◘	◘	◘	◘	◘	◘

5. Were effective mitigation strategies implemented?

Not at all		Moderate		Always	
0	1	2	3	4	NA/UNK
◘	◘	◘	◘	◘	◘

6. To what extent were the mitigation strategies successful?

Not		Moderate		Very	
0	1	2	3	4	NA/UNK
◘	◘	◘	◘	◘	◘

7. Was a comprehensive risk assessment process used prior to Front End Planning?

Not at all		Moderate		As Appropriate	
0	1	2	3	4	NA/UNK
◘	◘	◘	◘	◘	◘

8. To what extent was a comprehensive risk assessment process used prior to contract award?

Not at all		Moderate		Often	
0	1	2	3	4	NA/UNK
◘	◘	◘	◘	◘	◘

9. Was the process re-visited at a later time to evaluate if any risks should be upgraded of downgraded?

Not at all		Moderate		As needed	
0	1	2	3	4	NA/UNK
◘	◘	◘	◘	◘	◘

Please evaluate the overall effectiveness for each practice you used in this project.
Respond with NA if you did not use a best practice.

Project Risk Assessment

Project risk assessment is the process to identify, assess and manage risk. The project team evaluates risk exposure for potential project impact to provide focus for mitigation strategies.
On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of Project Risk Assessment*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

3.3 Team Building

Team Building is a project-focused process that builds and develops shared goals, interdependence, trust and commitment, and accountability among team members and that seeks to improve team members problem-solving skills.

Unless otherwise indicated, for each question select the single most appropriate response.

1. To what extent was a ***formal*** team building process used for this project?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. To what extent did upper management support the ***formal*** team building process (e.g. funding, training, etc.)?

Not at all		Moderately		Extensively	No formal team building used	
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. What was the level of involvement in the team building process of a facilitator who was external to this project?

None		Moderate		Extensive		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. To what extent were objectives of the team building process documented and clearly defined?

Very poorly or not at all		Moderately		Very well		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. To what extent were objectives of the team building process achieved?

Not at all		Moderately		Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

6. To what extent were new team members integrated into team building activities?

Not at all 0	1	Moderately 2	3	Extensively 4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

7. For each project phase, please indicate the extent that your company was involved in the team building process using a scale from 0 to 4, with 0 indicating not at all and 4 indicating extensively.

	Not at all 0	1	2	3	Extensively 4	NA	UNK
• Pre-Project Planning	◘	◘	◘	◘	◘	◘	◘
• Design	◘	◘	◘	◘	◘	◘	◘
• Procurement	◘	◘	◘	◘	◘	◘	◘
• Construction	◘	◘	◘	◘	◘	◘	◘
• Startup	◘	◘	◘	◘	◘	◘	◘

8. Please indicate the parties involved in the team building process? (Check all that apply)

◘Owner
◘Engineer(s) & Designer(s)
◘Constructor(s)
◘ Regulator(s)
◘Major Suppliers
◘ Subcontractor(s)
◘Construction Manager
◘Other. If other, please specify:

3.4 Alignment during Front End Planning

Alignment is the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives.

For each question, select the single most appropriate response as it pertains to the Front End Planning phase of the project.

1. Were the stakeholders (individuals and organizations who are involved in or may be affected by project activities) appropriately represented on the Project Team (e.g., operations, business management, construction, security, etc.)?

Not at all		Moderately		Very	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

2. How effective was project leadership in aligning team members to meet project objectives?

Not at all		Moderately		Very	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

3. How well were project objectives defined and prioritized (cost, quality, security & schedule)?

Poorly		Moderately		Very well	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

4. How effective was the communication within the team?

Not at all		Moderately		Very	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

5. How effective was the communication with stakeholders?

Not at all		Moderately		Very	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

6. How effective were team meetings in gaining alignment on project objectives?

Not at all		Moderately		Very productive	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

7. To what extent was a clear reward & recognition system implemented to meet identified project objectives?

Not at all		Moderately		Very well	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

8. How effectively were planning tools (e.g., aide-memoirs, analysis techniques, checklists, simulations, software programs, and work flow diagrams used to plan, develop, control and manage projects) used to promote alignment?

Not at all		Moderately		Very well	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

Please evaluate the overall effectiveness for each practice you used in this project. Respond with NA if you did not use a best practice.

Alignment during Front End Planning

Alignment is the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of Alignment during Front End Planning Practices*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

3.5 Design for Maintainability

Design for maintainability is the optimum use of facility maintenance knowledge and experience in the design/engineering of a facility to pertain the ease, accuracy, safety and economy in the performance of maintenance action; a design parameter related to the ability to maintain.

For each question select the single most appropriate response.

1. How well were corporate maintainability strategies and standards communicated on this project?

Not at all				Fully	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

2. Was a designated maintainability person integrated into the project team?

Not at all				Fully	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

3. To what extent were your organization's maintainability standards used in the project design?

Not at all				Fully	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

4. Were formal maintainability review sessions held with your facility maintenance organization?

Not at all		Sometimes		As Appropriate	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

5. Was a life cycle cost analysis tool used to determine equipment needs for the project?

No		Sometimes		Always	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

6. To what extent was computerized maintenance management system data used in making design decisions for this project?

Not at all				Fully	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

7. Were maintainability objectives and targets considered in the design process?

Not at all				Always	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

8. Were operations and maintenance input integrated into the design process?

No				Always	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

Please evaluate the overall effectiveness for each practice you used in this project. Respond with NA if you did not use a best practice.

Design for Maintainability

Design for maintainability is the optimum use of facility maintenance knowledge and experience in the design/engineering of a facility.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of Design for Maintainbility*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

3.6 Constructability

Constructability is the effective and timely integration of construction knowledge into the conceptual planning, design, construction and field operations of a project to achieve the overall project objectives with the best possible time and accuracy, at the most cost-effective levels.
For each question select the single most appropriate response.

1. To what extent was constructability implemented on this project?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. To what extent was constructability an element addressed in this project's formal written execution plan?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. Which of the following best describes how constructability principles were emphasized and communicated on this project? (Select only one)

◘No effort to emphasize and communicate

◘Minimum effort through informal means such as on-the-job training

◘Moderate effort as a component of ongoing management training (e.g. part of project management conference)

◘Substantial effort through structured and dedicated formal constructability training

◘Not Applicable

◘Unknown

4. On what basis was a constructability coordinator assigned to this project? (Select only one)

◘ No coordinator assigned

◘Assigned as a part-time responsibility

◘Assigned as a full-time responsibility

◘Not Applicable

◘Unknown

5. Which of the following best describes the constructability program documentation for this project? (Select only one)

- ◘None; no documentation existed.
- ◘Limited reference in any source (e.g. CII reference)
- ◘Project level constructability documents exist; may be included in other corporate documents
- ◘Project constructability manual is available, but neither widely used nor updated
- ◘Project constructability manual is available, widely used and periodically updated
- ◘Not Applicable
- ◘Unknown

6. Which of the following best describes the method(s) used to track lessons learned and saving/effects on this project due to the constructability program? (Select only one)

- ◘No tracking was used.
- ◘Ideas were conveyed via word of mouth and personal interaction; limited tracking of saving/effects
- ◘Some individual documentation existed; selected tracking of saving/ effects
- ◘System existed for capture and communication of lessons learned; extensive tracking of saving/effects
- ◘Not Applicable
- ◘Unknown

7. Please indicate the ***earliest time period*** of the first project meeting that deliberately and explicitly focused on constructability. Place a check below the ***earliest time period*** (Select only one).

Pre-Project Planning			Detail Design/ Procurement			Construction			NA	UNK
Early	Middle	Late	Early	Middle	Late	Early	Middle	Late		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

3.7 Materials Management

Materials management is an integrated process for planning and controlling all necessary efforts to make certain that the quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed. The materials management systems combine and integrate the takeoff, vendor evaluation, purchasing, expediting, warehousing, distribution, and disposing of materials functions.

Unless otherwise indicated, select the single most appropriate response for each question.

1. To what extent did this project have a ***designated*** materials management organization that was integrated across project teams?

Not at all				Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. How ***comprehensive*** was the ***written*** materials management plan for this project in addressing elements such as project goals, responsibility, cost & schedule, and transportation?

Not at all				Very Comprehensive		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. How extensively was the written materials management plan utilized throughout the life of the project?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. How adequate was the plan for addressing the effects of change orders on materials management?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. How extensively was an ***automated system*** (or integrated set of computer systems) used to identify, track, report, and facilitate control of project material throughout the life of the project?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

6. How effective was site materials management during the construction phase?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

7. How effective was the materials tracking and reporting system?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

8. How effective were purchasing plans & procedures over the life of the project?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

9. How effective were receipt and inspection procedures for critical materials and equipment?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

10. How adequate was the pre-qualification process for securing the appropriate suppliers of major equipment and materials?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

11. To what extent did the materials management plan utilize quality management practices?

Not at all				Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

12. How well were QA/QC plans implemented with the suppliers of major equipment and materials?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

13. Were there other activities that critically impacted your materials management?

No	Yes	NA	UNK
◘	◘	◘	◘

If yes, please list the activities and indicate whether the impact was positive or negative.

	Negative	Positive
________________________________	◘	◘

3.8 Project Change Management

Change Management is the process of incorporating a balanced change culture of recognition, planning and evaluation of project changes in an organization to effectively manage project changes.
Unless otherwise indicated, select the single most appropriate response for each question.

1. To what extent was a ***formal*** documented change management process used to ***actively*** manage changes on this project? Please answer for each phase.

Not at all — Moderately — Extensively

- Detailed Design

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

- Construction

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

- Startup

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. How often were major changes (i.e., those that exceed a project threshold) required to go through a formal change justification procedure?

Not at all		Sometimes		Always		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. Was authorization for change required before implementation?

No		Sometimes		Always		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. How timely was communication of change information to the proper disciplines and project participants?

Not at all		Moderately		Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. How well did the project contract identify the primary components and procedures of the project change management system?

Not at all		Moderately		Very well		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

6. To what extent were areas susceptible to change identified and evaluated for risk during review of the project design basis?

Not at all		Moderately		Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

7. To what extent were changes on this project evaluated against the business drivers and success criteria for the project?

Not at all		Moderately		Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

8. At what point were the criteria for change approval established and communicated to all project participants? Place ***a check*** below the earliest time period (Select only one).

Pre-Project Planning			Detail Design/ Procurement			Construction			NA	UNK
Early	Middle	Late	Early	Middle	Late	Early	Middle	Late		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

9. How often were changes managed against a baseline established at authorization or contract award?

Not at all		Sometimes		Always		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

10. At project close-out, how extensive was the evaluation of changes and their impact on the project cost and schedule performance for future use as lessons learned?

Not at all		Moderately		Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

11. Did project personnel settle, authorize, and execute change orders on this project in a timely manner?

Not at all		Sometimes		Always		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

12. To what extent does the formal change management process establish plans for mitigating cost and schedule impacts?

Not at all		Partially		Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3.9 Zero Accident Techniques

Zero accident techniques include the site specific safety programs and implementation, auditing and incentive efforts to create a project environment and a level of training that embraces the mind set that all accidents are preventable and that zero accidents is an obtainable goal.
For each question, select the single most appropriate response.

1. To what extent has an overall project safety plan been implemented?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. To what extent was safety a priority topic at pre-construction and construction meetings?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. To what extent was pre-task planning for safety conducted by contractor foremen or other site managers?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. How often were safety toolbox meetings held?

None	Monthly	Bi-weekly	Weekly	Daily	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. How often were safety audits performed by corporate safety personnel?

Annually or Less frequently	Quarterly	Monthly	Biweekly	Weekly	NA	UNK
◘	◘	◘	◘	◘	◘	◘

6. Which of the following best describes the time commitment of the site safety supervisor for this project?

No site safety supervisor	Part-time function	Full-time function	NA	UNK
◘	◘	◘	◘	◘

7. Overall how many workers per safety person were typically on site?

Over 200	151 to 200	71 to 150	21 to 70	1 to 20	NA	UNK
◘	◘	◘	◘	◘	◘	◘

8. What type of job-specific safety orientation was conducted for new contractor and subcontractor employees?

None	Informal	Formal	NA	UNK
◘	◘	◘	◘	◘

9. On average how much ongoing formal safety training did workers receive each month?

None	Less than 1 hr	1 hr but less than 4 hrs	4 hr but less than 7 hrs	Over 7 hrs	NA	UNK
◘	◘	◘	◘	◘	◘	◘

10. To what extent were safety incentives used?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

11. To what extent was safety performance utilized a criterion for contractor /subcontractor selection?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

12. How often were accidents formally investigated?

Not at all		Sometimes		Always		
0	1	2	3	4	No accidents occurred	UNK
◘	◘	◘	◘	◘	◘	◘

13. How often were near-misses formally investigated?

Not at all		Sometimes		Always		
0	1	2	3	4	None occurred	UNK
◘	◘	◘	◘	◘	◘	◘

14. How extensively was senior company management typically involved in the investigation of accidents?

Not at all · Moderately · Extensively

0	1	2	3	4	No accidents occurred	UNK
◘	◘	◘	◘	◘	◘	◘

15. Were pre-employment substance abuse tests for contractor employees conducted?

Never	Sometimes	Usually	Always	NA	UNK
◘	◘	◘	◘	◘	◘

16. Were contractor employees randomly screened for alcohol and drugs?

Not at all	Once a year or less	Twice a year or more	Quarterly or more	Monthly or more	NA	UNK
◘	◘	◘	◘	◘	◘	◘

17. Were substance abuse tests conducted after accidents?

Never	Sometimes	Usually	Always	No accidents occurred	UNK
◘	◘	◘	◘	◘	◘

18. Were ***reasonable cause substance abuse tests*** for contractor employees conducted?

Never	Sometimes	Usually	Always	NA	UNK
◘	◘	◘	◘	◘	◘

Reasonable cause test: An employee who is reasonably suspected of using alcohol or illegal drugs in the workplace or performing official duties while under the influence of alcohol or illegal drugs will be required to undergo an alcohol and drug test.

Please evaluate the overall effectiveness for each practice you used in this project. Respond with NA if you did not use a best practice.

Zero Accident Techniques

Zero accident techniques include the site specific safety programs and implementation, auditing and incentive efforts to create a project environment and a level of training that embraces the mind set that all accidents are preventable and that zero accidents is an obtainable goal.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of the Safety Program*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

3.10 Quality Management

Quality Management incorporates all activities conducted to improve the efficiency, contract compliance and cost effectiveness of design, engineering, procurement, QA/QC, construction, and start-up elements of construction projects.
Unless otherwise indicated, select the single most appropriate response for each question.

1. To what extent did your company implement a formal ***corporate*** Quality Management System (QMS)?

Not at all — Fully Implemented

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. (Owner Only) Rate the degree to which the engineering/construction QMS was considered in the selection process.

Not at all — Moderate — Extensive

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. To what extent were specific quality management goals & objectives included in the prime contract?

Not at all — Entirely

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. How extensively were quality management goals and objectives used to determine project reimbursement (e.g. Incentives)?

Not at all — Moderately — Extensively

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. Is the Quality Management System a budgeted item?

No	Yes	NA	UNK
◘	◘	◘	◘

6. To what degree was a formal ***project*** Quality Management System used on this project?

Not at all — Extensively

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

7. Please indicate the earliest time period of the project that quality management planning was initiated. Place a check below the earliest time period.

Pre-Project Planning			Detail Design/ Procurement			Construction			NA	UNK
Early	Middle	Late	Early	Middle	Late	Early	Middle	Late		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

8. How well was the Quality Management System communicated to key project personnel?

Not at all Very well

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

9. To what extent was the Quality Management System implemented by key project personnel?

Not at all Very well

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

10. To what extent were the following elements or resources used to implement the Quality Management system on this project?

Not Used Extensively Used

	0	1	2	3	4	NA	UNK
• External quality services	◘	◘	◘	◘	◘	◘	◘
• Internal quality manager	◘	◘	◘	◘	◘	◘	◘
• Discipline-specific quality program	◘	◘	◘	◘	◘	◘	◘
• Owner's procedures	◘	◘	◘	◘	◘	◘	◘
• Contractor's procedures	◘	◘	◘	◘	◘	◘	◘

11. Does the QA/QC manager for this project have external certification?

No	Yes	NA	UNK
◘	◘	◘	◘

12. To what extent were corrective actions implemented for root cause quality defects?

Not at all		Partially		Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

13. Which of the following quality management techniques were used on this project by your company? Check all that apply:

_____ Statistical methods
_____ Audits
_____ Quality cost tracking
_____ Quality circles/quality improvement teams
_____ Quality goals
_____ Team building / alignment
_____ Customer satisfaction measurement
_____ Quality assurance & quality control requirements
_____ Post project review
_____ Rejection rate analysis
_____ Reference documented quality policies and procedures (Quality manual, etc.)
_____ Lessons learned systems

14. What are the primary sources of quality problems on this project?
Check all that apply:

_____ Design Engineering
_____ Contractual
_____ Procurement/Materials Management
_____ Specifications
_____ Sub-Contracted scope of services
_____ Craft Labor
_____ Civil/Concrete
_____ Mechanical/Equipment
_____ Electrical/Instrumentation
_____ Piping
_____ Fit-up or Welding
_____ Start-up/Turnover of System
_____ Other(s)

3.11 Automation/Integration (AI) Technology

This section addresses ***the degree of automation/level of use and integration of automated systems*** for specific tasks/work functions common to most projects. Using the first matrix, please assess the degree of automation and level of use ***only***. Using the second matrix, please assess the level of integration of these automated systems among the tasks/work functions.

Referring to the use levels below, indicate how well for this project, the tasks/work functions were automated. Select the single most appropriate ***use level*** for the task/work functions listed.

USE LEVELS

- **Level 1(None/Minimal):** Little or no utilization beyond e-mail.
- **Level 2 (Some):** "Office" equivalent software, 2D CAD for detailed design.
- **Level 3 (Moderate):** Standalone electronic/automated engineering discipline (3D CAD) and project services systems.
- **Level 4 (Nearly Full):** Some automated input/output from multiple databases with automated engineering discipline design and project services systems.
- **Level 5 (Full):** Fully or nearly fully automated systems dominate execution of all work functions.

Automation of Task/Work Functions

	Use Level						
Task/Work Functions	1	2	3	4	5	NA	UNK
Business planning and analysis	◘	◘	◘	◘	◘	◘	◘
Conceptual definition & design	◘	◘	◘	◘	◘	◘	◘
Project (discipline) definition & facility design	◘	◘	◘	◘	◘	◘	◘
Supply management	◘	◘	◘	◘	◘	◘	◘
Project management							
Coordination system	◘	◘	◘	◘	◘	◘	◘
Communications system	◘	◘	◘	◘	◘	◘	◘
Cost system	◘	◘	◘	◘	◘	◘	◘
Schedule system	◘	◘	◘	◘	◘	◘	◘
Quality system	◘	◘	◘	◘	◘	◘	◘
Off-site/pre-construction	◘	◘	◘	◘	◘	◘	◘
Construction	◘	◘	◘	◘	◘	◘	◘
As-built documentation	◘	◘	◘	◘	◘	◘	◘
Facility start-up & life cycle support	◘	◘	◘	◘	◘	◘	◘

Referring to the use levels below, indicate how well for this project, the tasks/work functions were ***integrated across all other*** work functions. Select the single most appropriate ***integration level*** for the task/work functions listed.

USE LEVELS

- **Level 1(None/Minimal):** Little or no integration of electronic systems/applications.
- **Level 2 (Some):** Manual transfer of information via hardcopy of email.
- **Level 3 (Moderate):** Manual and some electronic transfer between automated systems.
- **Level 4 (Nearly Full):** Most systems are integrated with significant human intervention for tracking inputs/outputs.
- **Level 5 (Full):** All information is stored on a network system accessible to all automation systems and users. All routine communications are automated. The automated process and discipline design systems are fully integrated into 3D design, supply management, and project services systems (cost, schedule, quality, and safety).

Integration of Task/Work Functions

	Integration Level						
Task/Work Functions	1	2	3	4	5	NA	UNK
Business planning & analysis	◘	◘	◘	◘	◘	◘	◘
Conceptual definition & design	◘	◘	◘	◘	◘	◘	◘
Project (discipline) definition & facility design	◘	◘	◘	◘	◘	◘	◘
Supply management	◘	◘	◘	◘	◘	◘	◘
Project management							
Coordination system	◘	◘	◘	◘	◘	◘	◘
Communications system	◘	◘	◘	◘	◘	◘	◘
Cost system	◘	◘	◘	◘	◘	◘	◘
Schedule system	◘	◘	◘	◘	◘	◘	◘
Quality system	◘	◘	◘	◘	◘	◘	◘
Off-site/pre construction	◘	◘	◘	◘	◘	◘	◘
Construction	◘	◘	◘	◘	◘	◘	◘
As-built documentation	◘	◘	◘	◘	◘	◘	◘
Facility start-up & life cycle support	◘	◘	◘	◘	◘	◘	◘

3.12 Planning for Startup

Startup is the transitional phase between plant construction completion and commercial operations, including all of the activities that bridge these two phases. Planning for Startup consists of a sequence of activities that begins during requirements definition and extends through initial operations. This section assesses the level of Startup Planning by evaluating the degree of implementation of specific activities throughout the various phases of a project.

Please select the single most appropriate response to each question below.

1. How well were startup objectives communicated?

Not at all / Very well

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. To what extent was a formal startup execution plan implemented?

Not at all / Very extensive

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. To what extent were commissioning plans developed during planning for startup?

None were developed / Developed for All systems

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. How clearly were startup team key roles & responsibilities communicated?

Not at all / Very

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. To what extent was the startup schedule logic based on systems and sub-systems?

Not at all / Fully

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

6. To what extent was the startup schedule logic aligned with the EPC schedule?

Not at all / Fully

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

7. To what extent were startup needs incorporated in procurement requirements?

Not at all				Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

8. To what extent were suppliers for startup services pre-qualified?

Not at all				Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

9. Please indicate the ***earliest time period*** of the first project meeting that deliberately and explicitly focused on planning for startup. Place a check below the ***earliest time period*** (Select only one).

Pre-Project Planning			Detail Design/ Procurement			Construction			NA	UNK
Early	Middle	Late	Early	Middle	Late	Early	Middle	Late		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

10. How often were the startup risks assessed?

Not at all		Sometimes		Continuously		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

11. To what extent was formal operator/maintenance training conducted?

Not at all				Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

12. How extensive was the system turnover plan?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

13. To what extent were startup and Process Safety Management (PSM) procedures communicated?

Not at all				Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3.13 Prefabrication/ Preassembly/ Modularization (PPMOF)

To what extent did the project team consider prefabrication, preassembly or modularization?

Not at all				Fully	NA	UNK
0	1	2	3	4	◘	◘

2. To what extent did the project team consider the cost impact of using prefabrication, preassembly or modularization?

Not at all				Fully	NA	UNK
0	1	2	3	4	◘	◘

3. To what extent were labor availability and labor cost considered in evaluation of using prefabrication, preassembly or modularization?

Not at all				Fully	NA	UNK
0	1	2	3	4	◘	◘

4. To what extent were shipping routes and options considered in the prefabrication, preassembly or modularization decision?

Not at all				Fully	NA	UNK
0	1	2	3	4	◘	◘

5. To what extent were safety and quality issues considered in the prefabrication, preassembly or modularization decision?

Not at all				Fully	NA	UNK
0	1	2	3	4	◘	◘

6. To what extent was the construction schedule considered in the prefabrication, preassembly or modularization decision?

Not at all				Fully	NA	UNK
0	1	2	3	4	◘	◘

Please evaluate the overall effectiveness for each practice you used in this project. Respond with NA if you did not use a best practice.

Prefabrication/ Preassemble/ Modularization Effectiveness

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of the Prefabrication/ Preassembly/ Modularization*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

3.14 Workface Planning (WFP)

Workface Planning is the process of organizing and delivering all the elements necessary, before work is started, to enable craft persons to perform quality work in a safe, effective and efficient manner. *(More information about WFP on the COAA web site- http://www.coaa.ab.ca/BESTPRACTICES/ConstructionIndustryPerformance/WorkfacePlanning/tabid/96/Default.aspx)*

Was Workface Planning used in this project?

Yes ◘ No ◘

If "Yes", Please select the response below that best describes the level of implementation of workface planning in five critical areas:

- Field Installation Work Packages (FIWP)
- FIWP Planners
- EWP/ CWP Release Plan and Approvals
- Integration and Coordination of FIWP

Score each question using the following criteria:

- **Strongly Disagree** - The identified practice is not followed on this project.
- **Disagree** - We often fail to meet the requirement as defined by the practice on this project.
- **Neutral** - We follow the defined practice but inconsistently or consistently but not all the time
- **Agree** - We follow the defined practice consistently and meet the requirement most of the time.
- **Strongly Agree** - We follow the defined practice all the time.

Note: Please fill in "**Not Applicable**" to indicate if any element does not apply to your project.

Critical Areas		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	NA / UNK
A. Field Installation Work Packages (FIWP)							
A.1	Work is always packaged in Field Installation Work Packages (FIWP). *Clarification: An FIWP is a detailed scope of the work to be completed by a crew, over a specified period of time (usually a 1 to 4 week period).*	◘	◘	◘	◘	◘	◘
A.2	Dedicated Planner completes FIWP and signs-off as ready before FIWP is released to crew. *Clarification: An FIWP Checklist is discipline specific (civil, structural, piping, electrical, etc.) and itemizes all the information and documentation that should be part of the completed FIWP.*	◘	◘	◘	◘	◘	◘
B. Planners							
B.1	Dedicated planner(s) develop the Field Installation Work Packages (FIWP)? *Clarification: A dedicated planner spends virtually all of their time developing FIWP.*	◘	◘	◘	◘	◘	◘
C. EWP/CWP Release Plan and Approvals							

C.1	Engineering Work Package (EWP) identification and release plans are developed prior to the start of detailed engineering, which are reviewed and agreed to by the contractor or construction management.	◘	◘	◘	◘	◘	◘
C.2	Construction Work Package (EWP) identification and release plans are developed prior to the start of detailed engineering, which are reviewed and agreed to by engineering.	◘	◘	◘	◘	◘	◘
D. Integration and Coordination of FIWP							
D.1	Responsibility for integration planning was established to proactively resolve anticipated conflicts between individual FIWP's.	◘	◘	◘	◘	◘	◘
D.2	Responsibility for material coordination of individual FIWP's were assigned to a dedicated Coordinator(s).	◘	◘	◘	◘	◘	◘
D.3	Responsibility for specialty tools and construction equipment coordination for each FIWP was assigned to a dedicated Coordinator(s).	◘	◘	◘	◘	◘	◘

Combined WFP Score: ____%

Please evaluate the overall effectiveness for each practice you used in this project.
Respond with NA if you did not use a best practice.

Workface Planning

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of Workface Planning*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

4. Engineering Productivity Metrics

Instructions for Computation of Work-Hours and Rework-Hours

Work-hours are computed by the summation of all the account hours that are listed as **Direct** in the following table. All the account hours listed as **Indirect** are to be **excluded** from the work-hours that are submitted in the productivity data for the following sections.

Direct work-hours should include all detailed engineering hours used to produce deliverables including site investigations, meetings, planning, constructability, RFIs, etc., and rework. Specifically exclude work-hours for operating manuals and demolition drawings. Engineering work-hours reported should only be for the categories requested and may not equal the total engineering work-hours for the project.

Exclude the following categories: architectural design, plumbing, process design, civil/site prep, HVAC, insulation and paint, sprinkler/deluge systems, etc. Within a category, direct work-hours that cannot be specifically assigned into the provided classifications, and have not been excluded, should be prorated based on known work-hours or quantities as appropriate. Please review this table completely before providing data in the following sections.

	Direct	Indirect
Account	Discipline Engineer	Document Control
	Designer	Reproduction Graphics
	Technician	Project Management
		Project Controls (cost/schedule/estimating)
		Project Engineer
		Secretary/clerk
		Procurement (supply management)
		Construction Support (test package support, commissioning, etc.)
		Quality Assurance
		Accounting
		Legal

Unit of Measure Legend:

cm.	centimeter	SM	Square Meter	WH	Work-hour
mm.	millimeter	MT	Metric Ton	HP	Horse Power
LM	Linear Meter	CM	Cubic Meter	kW	kilo-watts

4.1 Concrete

Instructions
Please complete the following tables indicating quantity and engineering work-hours for the categories appropriate to your project. If you cannot enter all data then enter totals only. Include rework in the work-hours only. If the project had no workhours or quantities for a category, enter none.
The quantity of concrete is that concrete that is required for the specified slab, foundation, or structure provided in the final Issued for Construction (IFC) drawings.
Refer to the section "Instructions for Computation of Work-Hours and Rework-Hours" for a detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the work-hours.
Which design platform was used for this category in this project? Check all that apply.
2D ( )
3D ( )

Slabs	**None**	**IFC Quantity (cubic yards)**	**Engineering Work-Hours (including rework) (hours)**
Ground & Supported Slabs			
Area Paving			
Total Slabs			

Foundations	**None**	**IFC Quantity (cubic yards)**	**Engineering Work-Hours (including rework) (hours)**
Foundations (< 5CY)			
Foundations (>= 5CY)			
Total Foundations (CY) **(Excluding piling)**			

Concrete Structures	**None**	**IFC Quantity (cubic yards)**	**Engineering Work-Hours (including rework) (hours)**
Concrete Structures			
This includes concrete structures, columns, beams, cooling tower basins, trenches, formed elevated slabs/structures, retaining walls, and drainage structures.			

Total Concrete	**None**	**IFC Quantity (cubic yards)**	**Engineering Work-Hours (including rework) (hours)**
Total Concrete			
The total concrete quantity and work hours may be **greater than** the sum of totals for slabs, foundations and concrete structures if the project included concrete not in these categories.			

4.2 Structural Steel

Instructions

Please complete the following tables indicating quantity and engineering work-hours for the categories appropriate to your project. If possible, separate data for structural steel, pipe racks & utility bridges and miscellaneous steel. If you can not separate structural steel from pipe racks & utility bridges, combine these data in the space provided below. If you cannot enter all data then enter totals only. Include rework in the work-hours only. If the project had no workhours or quantities for a category, enter none.

The quantity of steel is that quantity of steel provided in the final Issued for Construction (IFC) drawings.

Refer to the section "Instructions for Computation of Work-Hours and Rework-Hours" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the work-hours.

Which design platform was used for this category in this project? Check all that apply.
2D ( )
3D ( )

Structural Steel	None	IFC Quantity (tons)	Engineering Work-Hours (including rework) (hours)
Structural Steel			
This includes trusses, columns, girders, beams, struts, girts, purlins, vertical and horizontal bracing, bolts, and nuts.			
Pipe Racks & Utility Bridges			
This includes steel structures outside the physical boundaries of a major structure, which are used to support pipe, conduit, and/or cable tray.			
Combined Structural Steel / Pipe Racks & Utility Bridges*			
* Enter combined structural steel and pipe racks & utility bridges if you cannot separate the quantities above.			
Miscellaneous Steel			
This includes handrails, toeplate, grating, checker plate, stairs, ladders, cages, miscellaneous platforms, pre-mounted ladders and platforms, miscellaneous support steel including scab on supports, "T" and "H" type supports, trench covers, and Q decking.			
Total Steel			
This is the total of structural steel, pipe racks & utility bridges, and miscellaneous steel from above or the total of combined structural steel, pipe racks & utility bridges (if not separated) and miscellaneous steel. If you have quantities for steel not included in the breakouts above, include them in the totals here.			

4.3 Piping

Instructions

Please complete the following tables indicating quantity, percent hot and cold, and engineering work-hours for the categories appropriate to your project. Piping includes under ground pressure pipe. **Exclude tubing**. If you cannot enter all data then enter totals only. Include rework in the work-hours only. If the project had no workhours or quantities for a category, enter none.

The quantity of piping is that piping specified in the final Issued for Construction (IFC) drawings. This quantity should not be "cut lengths" but should be measured "center-to-center" through valves and fittings as with the quantity for the construction metric. Most "CADD dumps" are cut lengths. The quantity should be adjusted to be the length measured as noted above.

Refer to the section "Instructions for Computation of Work-Hours and Rework-Hours" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the work-hours.

Hot piping is that piping which has a design temperature greater than 250 degrees Fahrenheit. **Cold piping** is that piping which has a design temperature less than minus 20 degrees Fahrenheit.

Which design platform was used for this category in this project? Check all that apply.

2D ( )
3D ( )

Piping	None	IFC Quantity	Percent Hot and Cold (%)	Engineering Work-Hours (including rework) (hours)
Small Bore **(2-1/2" and Smaller)** (linear feet)				
Large Bore (3" and Larger) (linear feet)				
Engineered Hangers and Supports (each) (Includes stress analysis)				
Number of pipe fittings*				
Total Piping **(linear feet only)**				

* Elbows, flanges, reducers, branch connection fittings e.g. o-lets, saddles etc., Y's, T's, caps, unions, couplings, etc.
** Total piping quantity is linear feet only. The total piping work-hours include those hours for small & large bore piping, engineered hangers and supports and fittings.

5. Construction Productivity Metrics

Instructions for Computation of Actual Work-Hours, Rework-Hours, and Installed Costs

Actual work-hours are computed by the summation of all the account hours that are listed as **Direct** in the following table. All the account hours listed as **Indirect** are to be **excluded** from the actual work-hours tha are submitted in the productivity data for the following sections.

Estimated quantities and work-hours should be updated to include all change orders. **Actuals** include al quantities installed and work-hours, to include rework-hours for these quantities.

Total installed unit cost (TIUC) is defined as the burdened cost of **direct labour, bulk material, fina asset equipment, and civil and sitework equipment by pro rata share** including **overhead and profi from both direct hire and subcontract.** Burden cost of direct labour includes insurance, welfare and othe fund and charges associated to labour by regulations.

The **direct labour costs** are those associated with work-hours by craft persons listed as **Direct** in the following table.

	Direct	Indirect	
Account	Direct Craft Labour	Accounting	Procurement
	Foreman	Area Superintendent	Process Equipment Maintenance
	General Foreman	Assistant Project Manager	Project Controls
	Load and Haul	Bus Drivers	Project Manager
	Oilers	Clerical	QA/QC
	Operating Engineer	Craft Planners	Quantity Surveyors
	Safety Meetings	Craft Superintendent	Receive and Offload
	Scaffolding	Craft Training	Recruiting
	Truck Drivers Direct	Crane Setup/take down	Safety
		Document Control	Safety Barricades
		Drug Testing	Security
		Equipment Coordinator	Show-up/Travel Time
		Evacuation Time	Site Construction Manager
		Field Administration Staff	Site Maintenance
		Field Engineer-Project	Subcontract Administrator
		Field Staff (Hourly)	Supervision (Hourly)
		Field Staff (Salary)	Surveying Crews
		Fire Watch	Temporary Facilities
		Flag Person	Temporary Utilities
		General Superintendent	Test Welders
		Hole Watch	Tool Room
		Janitorial	Truck Drivers Indirect
		Job Clean-Up	Warehouse
		Master Mechanic	Warehousing
		Material Control	Water Hauling
		Mobilization	
		Nomex Distribution	
		Orientation Time	
		Payroll Clerks/ Timekeepers	

Unit of Measure Legend:

cm.	centimeter	SM	Square Meter	WH	Work-hour
mm.	millimeter	MT	Metric Ton	HP	Horse Power
LM	Linear Meter	CM	Cubic Meter	kW	kilo-watts

5.1 Concrete

Instructions

Please provide estimated and actual productivity below for the categories appropriate to your project for the installation of concrete.

In the first section of each category include the ***estimated quantity to be installed***, the ***estimated work-hours*** required for the installation and the ***estimated total installed unit cost (TIUC) at the time of project sanction*** (or as soon as available following sanction).

In the second section for each category, provide the ***actual installed neat quantity***, the ***work-hours (including rework)***, and the ***actual total installed unit cost (TIUC).*** Indicate if the work performed for each category was subcontracted or not. If work was both subcontracted and in-house, indicate the type that was more predominant.

Total installed unit cost (TIUC) is defined as the burdened cost of **direct labour, bulk material , final asset equipment, and civil and sitework equipment by pro rata share** including **overhead and profit from both direct hire and subcontract.** Burden cost of direct labour includes insurance, welfare and other fund and charges associated to labour by regulations.

<u>Include work-hours for the following selected activities:</u>
Loading material at the jobsite yard, hauling to, and unloading at the job work site; local layout, excavation and backfill, fabrication, installation, stripping and cleaning forms; field installation of reinforcing material; field installation of all embeds; all concrete pours, curing, finishing, rubbing, mud mats; and anchor bolt installation.

<u>Do not include work-hours for:</u>
Piling, drilled piers, wellpoints and major de-watering, concrete fireproofing, batch plants, non-permanent roads and facilities, third party testing, mass excavations, rock excavations, site survey, q-deck, sheet piles, earthwork shoring, cold pour preparation, grouting, precast tees, panels, decks, vaults, manholes, etc.

Definitions

The **Installed Neat Quantity** of concrete is the amount of concrete that is required for the specified slab, foundation, or structure provided in the project's plans and specifications and does not include any quantity of concrete that is used due to rework.

Refer to the section "**Instructions for Computation of Actual Work-Hours, Rework-Hours and Installed Cost**" for a detailed listing of direct hours and their associated costs to be included as well as indirect hours and their associated costs to be excluded.

Overall, please indicate the percentage amount of concrete material and/or equipment procured by owners %

Slabs	Estimated Productivity			
	None	Quantity (CM)	WH	Total Installed Unit Cost ($/CM)
On-Grade				
Elevated Slabs /On Deck				
Area Paving				
Total Slabs				
Total Installed Unit Cost (TIUC) for Total Slabs is the weighted average by quantity of the On-Grade, Elevated Slabs/ On Deck, Area Paving and any other slabs not included above.				

Slabs	Actual Productivity				
	None	Sub contracted (Yes or No)	Installed Quantity (CM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/CM)
On-Grade					
Elevated Slabs /On Deck					
Area Paving					
Total Slabs					
Total Installed Unit Cost (TIUC) for Total Slabs is the weighted average by quantity of the On-Grade, Elevated Slabs/ On Deck, Area Paving and any other slabs not included above.					

Foundations	Estimated Productivity			
	None	Quantity (CM)	WH	Total Installed Unit Cost ($/CM)
< 4 CM				
4 – 15 CM				
16– 38 CM				
≥ 38 CM				
Total Foundations				
Total Installed Unit Cost (TIUC) for Total Foundations is the weighted average by quantity of the each category above.				

Foundations	Actual Productivity				
	None	Sub contracted (Yes or No)	Installed Quantity (CM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/CM)
< 4 CM					
4 – 15 CM					
16– 38 CM					
≥ 38 CM					
Total Foundations					
Total Installed Unit Cost (TIUC) for Total Foundations is the weighted average by quantity of the each category above.					

Concrete Structures	Estimated Productivity			
	None	Quantity (CM)	WH	Total Installed Unit Cost ($/CM)
Concrete Structures				

Concrete Structures	Actual Productivity				
	None	Sub contracted (Yes or No)	Installed Quantity (CM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/CM)
Concrete Structures					

Total Concrete	Estimated Productivity			
	None	Quantity (CM)	WH	Total Installed Unit Cost ($/CM)
Total Concrete				
Total Installed Unit Cost (TIUC) for Total Concrete is the weighted average by quantity of the total slabs, total foundations, total concrete structures and any other concrete not included above.				

Total Concrete	Actual Productivity				
	None	Sub contracted (Yes or No)	Installed Quantity (CM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/CM)
Total Concrete					
Total Installed Unit Cost (TIUC) for Total Concrete is the weighted average by quantity of the total slabs, total foundations, total concrete structures and any other concrete not included above.					

Concrete Repetitive Construction

If the project includes multiple similar components that allow construction efficiencies (i.e. based on learning curve, formwork reuse, etc.), estimate the percentage of the total quantity for concrete that was repeated.

Example: The total concrete quantity for a project is 5,000 CM. The design includes three identical foundations of 1,000 CM each. There are no other identical components. The estimated repeated quantity for concrete is:

$$\frac{3(1{,}000) - 1{,}000\ CM}{5{,}000\ CM} = \frac{2000\ CM}{5{,}000\ CM} = 40\%$$

No Response

< 10%	≥ 10%	> 20%	>30%	> 40%	>50%	> 60%	> 70%	> 80%	> 90%

5.2 Structural Steel

Instructions

Please provide estimated and actual productivity below for the categories appropriate to your project for the installation of structural steel.

In the first section of each category include the ***estimated quantity to be installed***, the ***estimated work-hours*** required for the installation and the ***estimated total installed unit cost (TIUC) at the time of project sanction*** (or as soon as available following sanction).

In the second section for each category, provide the ***actual installed neat quantity***, the ***work-hours (including rework),*** and the ***actual total installed unit cost (TIUC).*** Indicate if the work performed for each category was subcontracted or not. If work was both subcontracted and in-house, indicate the type that was more predominant.

Total installed unit cost (TIUC) is defined as the burdened cost of **direct labour, bulk material, final asset equipment, and civil and sitework equipment by pro rata share** including **overhead and profit from both direct hire and subcontract.** Burden cost of direct labour includes insurance, welfare and other fund and charges associated to labour by regulations.

<u>Include work-hours for the following selected activities:</u>
Shake-out, transporting, erection, plumbing, leveling, bolting, and welding.

Do not include work-hours for:
Fabrication, demolition, and architectural work, such as roofing, siding and vents.

Definitions

The **Installed Quantity** of steel is the amount of steel provided in the project's plans and specifications and does not include any quantity of steel that is used due to rework.

Refer to the section "**Instructions for Computation of Actual Work-Hours, Rework-Hours and Installed Cost**" for a detailed listing of direct hours and their associated costs to be included as well as indirect hours and their associated costs to be excluded.

Overall, please indicate the percentage amount of structural steel material and equipment procured by the owner. ____ %

Structural Steel	Estimated Productivity			
	None	Quantity (MT)	WH	Total Installed Unit Cost ($/MT)
Structural Steel				
This includes trusses, columns, girders, beams, struts, girts, purlins, vertical and horizontal bracing, bolts, and nuts.				
Pipe Racks & Utility Bridges				
This includes steel structures outside the physical boundaries of a major structure, which is used to support pipe, conduit, and/or cable tray.				
Miscellaneous Steel				
This includes handrails, toe plate, grating, checker plate, stairs, ladders, cages, miscellaneous platforms, pre-mounted ladders and platforms, miscellaneous support steel including scab on supports, "T" and "H" type supports, trench covers, and Q decking.				
Total Structural Steel				
Total Installed Unit Cost (TIUC) for Structural Steel is the weighted average by quantity of Structural Steels, Pipe Racks & Utility Bridges, Miscellaneous Steel and any other Structural Steel not included above.				

Structural Steel	Actual Productivity				
	None	Sub contracted (Yes or No)	Installed Quantity (MT)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/ MT)
Structural Steel					
This includes trusses, columns, girders, beams, struts, girts, purlins, vertical and horizontal bracing, bolts, and nuts.					
Pipe Racks & Utility Bridges					
This includes steel structures outside the physical boundaries of a major structure, which is used to support pipe, conduit, and/or cable tray.					
Miscellaneous Steel					
This includes handrails, toe plate, grating, checker plate, stairs, ladders, cages, miscellaneous platforms, pre-mounted ladders and platforms, miscellaneous support steel including scab on supports, "T" and "H" type supports, trench covers, and Q decking.					
Total Structural Steel					
Total Installed Unit Cost (TIUC) for **Structural Steel** is the weighted average by quantity of Structural Steels, Pipe Racks & Utility Bridges, Miscellaneous Steels and any other Structural Steel not included above.					

Structural Steel Repetitive Construction

If the project includes multiple similar components that allow construction efficiencies (i.e. based on learning curve, formwork reuse, etc.), estimate the percentage of the total quantity for structural steel that was repeated.

Example: The total structural steel quantity for a project is 5,000 MT. The design includes three identical structural steel frames of 1,000 MT each. There are no other identical components. The estimated repeated quantity for structural steel is :

$$\frac{3(1{,}000)-1{,}000\text{ MT}}{5{,}000\text{ MT}} = \frac{2{,}000\text{ MT}}{5{,}000\text{ MT}} = 40\%$$

No Response									
< 10%	≥ 10%	> 20%	>30%	> 40%	>50%	> 60%	> 70%	> 80%	> 90%

5.3 Electrical

Instructions

Please provide estimated and actual productivity below for the categories appropriate to your project for the installation of electrical.

In the first section of each category include the ***estimated quantity to be installed***, the ***estimated work-hours*** required for the installation and the ***estimated total installed unit cost (TIUC) at the time of project sanction*** (or as soon as available following sanction).

In the second section for each category, provide the ***actual installed neat quantity***, the ***work-hours (including rework),*** and the ***actual total installed unit cost (TIUC).*** Indicate if the work performed for each category was subcontracted or not. If work was both subcontracted and in-house, indicate the type that was more predominant.

Total installed unit cost (TIUC) is defined as the burdened cost of **direct labour, bulk material, final asset equipment, and civil and sitework equipment by pro rata share** including **overhead and profit from both direct hire and subcontract.** Burden cost of direct labour includes insurance, welfare and other fund and charges associated to labour by regulations.

<u>Include work-hours for the following selected activities:</u>
Installation, testing, labeling, etc.

Definitions

The **Installed Quantity** of electrical equipment, devices, conduit and cable trays are the amount of each provided in the project's plans and specifications and does not include any quantity that is used due to rework.

Refer to the section "**Instructions for Computation of Actual Work-Hours, Rework-Hours and Installed Cost**" for a detailed listing of direct hours and their associated costs to be included as well as indirect hours and their associated costs to be excluded.

- Total Direct Electrical Work-Hours for This Project _________
- Total Connected Horsepower of Motors _________
- Number of Motors _________
- Total KVA Load of Project _________

Overall, please indicate the percentage amount of electrical material and equipment procured by the owner.
____ %

Electrical Equipment and Devices	Estimated Productivity			
	None	Quantity (each)	WH	Total Installed Unit Cost ($/Each)
Panels and Small Devices				
This includes all labour for the installation of lighting and power panels, dry type transformers, control stations (pushbuttons, small local panels, etc.), welding receptacles and their supports. Count includes only actual electrical devices - not supports.				
Electrical Equipment 1kV & Below				
Electrical Equipment Over 1kV				
Total Electrical Equipment				
- This includes all labour for the installation of transformers, switchgear, UPS systems, MCCs, DCS/PLC racks and panels, etc. - Total Installed Unit Cost (TIUC) for **Electrical Equipment** is the weighted average by quantity of Electrical Equipments 1kV & Below, Electrical Equipments Over 1kV.				

Electrical Equipment and Devices	Actual Productivity				
	None	Sub contracted (Yes or No)	Installed Quantity (each)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/Each)
Panels and Small Devices					
This includes all labour for the installation of lighting and power panels, dry type transformers, control stations (pushbuttons, small local panels, etc.), welding receptacles and their supports. Count includes only actual electrical devices - not supports.					
Electrical Equipment 1kV & Below					
Electrical Equipment Over 1kV					
Total Electrical Equipment					
- This includes all labour for the installation of transformers, switchgear, UPS systems, MCCs, DCS/PLC racks and panels, etc. - Total Installed Unit Cost (TIUC) for **Electrical Equipment** is the weighted average by quantity of Electrical Equipments 1kV & Below, Electrical Equipments Over 1kV.					

Instructions for calculation of Weighted-Average Diameter of Conduit (Hyperlink)

Conduit	Weighted Average Diameter (inches)	Estimated Productivity			
		None	Quantity (LM)	WH	Total Installed Unit Cost ($/LM)
Exposed or Aboveground Conduit					
This includes all labour for installation of conduit, hangers, supports, fittings, flexible connections, marking, grounding jumpers, seals, boxes, etc. This excludes lighting conduit.					
Underground, Duct Bank or Embedded Conduit					
This includes all labour for installation of conduit, supports, grounding jumpers, etc. Does not include excavation, backfill, concrete, manholes, etc.					
Total Conduit					
- Total Installed Unit Cost (TIUC) for **Conduit** is the weighted average by quantity of Exposed or Aboveground Conduits, Underground, Duct Bank or Embedded Conduit.					

Conduit	Weighted Average Diameter (inches)	Actual Productivity				
		None / Sub Contracted (Yes or No)	Installed Quantity (LM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/LM)
Exposed or Aboveground Conduit					
This includes all labour for installation of conduit, hangers, supports, fittings, flexible connections, marking, grounding jumpers, seals, boxes, etc. This excludes lighting conduit.					
Underground, Duct Bank or Embedded Conduit					
This includes all labour for installation of conduit, supports, grounding jumpers, etc. Does not include excavation, backfill, concrete, manholes, etc.					
Total Conduit					
- Total Installed Unit Cost (TIUC) for **Conduit** is the weighted average by quantity of Exposed or Aboveground Conduits, Underground, Duct Bank or Embedded Conduit.					

Instructions for calculation of Weighted-Average Size of Cable Tray (Hyperlink)

Cable Tray	Weighted Average Size (inches)	Estimated Productivity		
		None	Quantity (LM) / WH	Total Installed Unit Cost ($/LM)
Cable Tray				

- This includes all labour for the installation of tray, channel, supports, covers, grounding jumpers, marking, etc. Includes cable tray for instrument cable but does not include fire stop.

Cable Tray	Weighted Average Size (inches)	None	Actual Productivity			
			Sub Contracted (Yes or No)	Installed Quantity (LM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/LM)
Cable Tray						
This includes all labour for the installation of tray, channel, supports, covers, grounding jumpers, marking, etc. Includes cable tray for instrument cable but does not include fire stop.						

Wire and Cable	Estimated Productivity	
	None / Quantity (LM) / WH	Total Installed Unit Cost ($/LM)
Control Cable		
Power Cable below 1kV		
Power Cable above 1kV		
This includes all labour for the installation, termination, labeling, and testing of 1kV and below power and control cable. It does not include heat-tracing cable.		
Total Wire and Cable		
- Total Installed Unit Cost (TIUC) for **Wire and Cable** is the weighted average by quantity of Control Cables, Power Cable below 1kV, Power Cable above 1kV and any other listed above.		

Wire and Cable	Actual Productivity				
	None	Sub Contracted (Yes or No)	Installed Quantity (LM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/LM)
Control Cable					
Power Cable below 1kV					
Power Cable above 1kV					
This includes all labour for the installation, termination, labeling, and testing of 1kV and below power and control cable. It does not include heat-tracing cable.					
Total Wire and Cable					
- Total Installed Unit Cost (TIUC) for **Wire and Cable** is the weighted average by quantity of Control Cables, Power Cable below 1kV, Power Cable above 1kV listed above.					

Transmission Line	Estimated Productivity			
	None	Quantity (LM)	WH	Total Installed Unit Cost ($/LM)
High Voltage above 25kV				
This includes all labour for the installation of line, tower, foundations, switch yards and testing of power and control line.				
Total Transmission Line				

Transmission Line	Actual Productivity				
	None	Sub Contracted (Yes or No)	Installed Quantity (LM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/LM)
High Voltage above 25kV					
This includes all labour for the installation of line, tower, foundations, switch yards and testing of power and control line.					
Total Transmission Line					

Other Electrical	Estimated Productivity			
	None	Quantity	WH	Total Installed Unit Cost ($/each or $/LM)
Lighting Fixtures (each)				
This includes all labour for the installation of fixtures (including lamps and supports) and for the installation of conduit and wiring from the lighting panel to the fixtures. Includes any control equipment, switches, conduit, wiring and accessories installed on the load side of the lighting panel. Installation of lighting panels is included in Panels and Small Devices and power feeder wiring for the panel is included in Power and Control Cable – 1kV.				
Grounding (LM)				
This includes all the labour for the installation of cable, ground rods, connectors and all accessories for the installation of conduit and wiring from the lighting panel to the fixtures. Includes work-hours for the installation of ground cables pulled into cable trays, duct banks, and installed exposed in electric or other rooms. The Length is based on the total meters of ground cable installed.				
Electrical Heat Tracing (LM)				
This includes the labour for the installation of electric heat trace cable, power feeds to the cable, control accessories, end of line devices, connectors, tape or other strapping/support materials, and any other items needed to complete the heat trace system. Length is based on the total meters of process and utility piping heat traced.				

Other Electrical	Actual Productivity				
	None	**Sub Contracted (Yes or No)**	**Installed Quantity**	**Actual WH (including rework) (hours)**	**Total Installed Unit Cost ($/each or $/LM)**
Lighting Fixtures (each)					
This includes all labour for the installation of fixtures (including lamps and supports) and for the installation of conduit and wiring from the lighting panel to the fixtures. Includes any control equipment, switches, conduit, wiring and accessories installed on the load side of the lighting panel. Installation of lighting panels is included in Panels and Small Devices and power feeder wiring for the panel is included in Power and Control Cable – 1kV.					
Grounding (LM)					
This includes all the labour for the installation of cable, ground rods, connectors and all accessories for the installation of conduit and wiring from the lighting panel to the fixtures. Includes work-hours for the installation of ground cables pulled into cable trays, duct banks, and installed exposed in electric or other rooms. The Length is based on the total meters of ground cable installed.					
Electrical Heat Tracing (LM)					
This includes the labour for the installation of electric heat trace cable, power feeds to the cable, control accessories, end of line devices, connectors, tape or other strapping/support materials, and any other items needed to complete the heat trace system. Length is based on the total meters of process and utility piping heat traced.					

5.4 Piping

Instructions

Please provide estimated and actual productivity below for the categories appropriate to your project for the installation of piping.

In the first section of each category include the ***estimated quantity to be installed***, the ***estimated work-hours*** required for the installation and the ***estimated total installed unit cost (TIUC) at the time of project sanction*** (or as soon as available following sanction).

In the second section for each category, provide the ***actual installed neat quantity***, the ***work-hours (including rework),*** and the ***actual total installed unit cost (TIUC).*** Indicate if the work performed for each category was subcontracted or not. If work was both subcontracted and in-house, indicate the type that was more predominant.

Total installed unit cost (TIUC) is defined as the burdened cost of **direct labour, bulk material, final asset equipment, and civil and sitework equipment by pro rata share** including **overhead and profit from both direct hire and subcontract.** Burden cost of direct labour includes insurance, welfare and other fund and charges associated to labour by regulations.

Include work-hours for the following selected activities:
Erecting and installing large bore piping, including welding, valves, in-line specials, flushing/hydro testing, tie-ins (excluding hot taps), material handling (from the laydown yard to the field), in-line devices, specialties, equipment operators, and hangers & supports.

Do not include work-hours for:
Non-destructive evaluation (NDE), steam tracing, stress relieving, offloading pipe as it is received, commissioning, and field fabrication of large bore.

Definitions

The **Installed Quantity** of piping is the amount of piping specified in the project's plans and specifications and does not include any quantity of piping that is used due to rework.

%Shop Fabricated is the percentage of offsite fabricated pipe from the total pipe installed by length. *The shop fabrication does not include on-site, field fabricated pipe.*

Refer to the section "**Instructions for Computation of Actual Work-Hours, Rework-Hours and Installed Cost**" for a detailed listing of direct hours and their associated costs to be included as well as indirect hours and their associated costs to be excluded.

Overall, please indicate the percentage amount of piping material and equipment procured by owner. ____ %

Instructions for calculation of Small Bore Weighted Diameter (Hyperlink)

Small Bore (2-1/2" and Smaller)

Include only onsite workhours: Field fabricated and installation workhours **(Excludes Tubing)**

Small Bore	Weighted Diameter (inches)	Percent Shop Fabricated (%)	Estimated Productivity			
			None	Quantity (LM)	WH	Total Installed Unit Cost ($/LM)
Carbon Steel						
Stainless Steel						
Chrome						
Other Alloys						
Non Metallic						
Total Small Bore						
- Total Installed Unit Cost (TIUC) for **Small Bore** is the weighted average by quantity of types of small bore listed above and any other small bore not listed above.						

Small Bore	Weighted Diameter (inches)	Percent Shop Fabricated (%)	Actual Productivity				
			None	Sub Contracted (Yes or No)	Installed Quantity (LM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/LM)
Carbon Steel							
Stainless Steel							
Chrome							
Other Alloys							
Non Metallic							
Total Small Bore							
- Total Installed Unit Cost (TIUC) for **Small Bore** is the weighted average by quantity of types of small bore listed above and any other small bore not listed above.							

In the following section for large bore piping, the following definitions apply for hot and cold piping: Hot piping is that which has a design temperature greater than 121 degrees Celsius. Cold Piping is that which has a design temperature less than minus 28 degrees Celsius.

Instructions for calculation of ISBL and OSBL Large Bore Weighted Diameter (Hyperlink)

Inside Battery Limits (ISBL) Large Bore (3" and Larger) (Excludes Tubing)

Within a ISBL facility, there are above ground and below ground piping systems. These should **BOTH** be included in the ISBL section. Underground can include Process Systems, and a small amount of drainage systems.

Estimated Productivity

Large Bore (ISBL)	None	Weighted Diameter (inches)	Average Schedule	Quantity (LM)	WH	% Shop Fabricated	Total Installed Unit Cost ($/LM)
Carbon Steel							
Stainless Steel							
Chrome							
Other Alloys							
Non Metallic							
Total Large Bore (ISBL)							
- Total Installed Unit Cost (TIUC) for **Large Bore (ISBL)** is the weighted average by quantity of types of large bore listed above and any other large bore pipe not listed above.							

Actual Productivity

Large Bore (ISBL)	None	Sub contracted (Yes or No)	Weighted Diameter (inches)	Average Schedule	Installed Quantity (LM)	Actual WH (including rework) (hours)	% Shop Fabricated	Total Installed Unit Cost ($/LM)
Carbon Steel								
Stainless Steel								
Chrome								
Other Alloys								
Non Metallic								
Total Large Bore (ISBL)								
- Total Installed Unit Cost (TIUC) for **Large Bore (ISBL)** is the weighted average by quantity of types of large bore listed above and any other large bore pipe not listed above.								

Outside Battery Limits (OSBL) Large Bore (3" and Larger) (Excludes Tubing)

Within an OSBL facility, there are above ground and below ground piping systems. These should **BOTH** be included in the OSBL section.

Estimated Productivity

Large Bore (OSBL)	None	Weighted Diameter (inches)	Average Schedule	Quantity (LM)	WH	% Shop Fabricated	Total Installed Unit Cost ($/LM)
Carbon Steel							
Stainless Steel							
Chrome							
Other Alloys							
Non Metallic							
Total Large Bore (OSBL)							
- Total Installed Unit Cost (TIUC) for **Large Bore (OSBL)** is the weighted average by quantity of types of large bore listed above and any other large bore not listed above.							

Actual Productivity

Large Bore (ISBL)	None	Sub contracted (Yes or No)	Weighted Diameter (inches)	Average Schedule	Installed Quantity (LM)	Actual WH (including rework) (hours)	% Shop Fabricated	Total Installed Unit Cost ($/LM)
Carbon Steel								
Stainless Steel								
Chrome								
Other Alloys								
Non Metallic								
Total Large Bore (OSBL)								
- Total Installed Unit Cost (TIUC) for **Large Bore (OSBL)** is the weighted average by quantity of types of large bore listed above and any other large bore not listed above.								

Heat Tracing Tubing	Estimated Productivity			
	None	Quantity (LM)	WH	Total Installed Unit Cost ($/LM)
Total Heat Tracing Tubing				

Heat Tracing Tubing	Actual Productivity				
	None	Sub Contracted (Yes or No)	Installed Quantity (LM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/LM)
Total Heat Tracing Tubing					

5.5 Instrumentation

Instructions

Please provide estimated and actual productivity below for the categories appropriate to your project for the installation of instrumentation.

In the first section of each category include the ***estimated quantity to be installed***, the ***estimated work-hours*** required for the installation and the ***estimated total installed unit cost (TIUC) at the time of project sanction*** (or as soon as available following sanction).

In the second section for each category, provide the ***actual installed neat quantity***, the ***work-hours (including rework),*** and the ***actual total installed unit cost (TIUC).*** Indicate if the work performed for each category was subcontracted or not. If work was both subcontracted and in-house, indicate the type that was more predominant.

Total installed unit cost (TIUC) is defined as the burdened cost of **direct labour, bulk material, final asset equipment, and civil and sitework equipment by pro rata share** including **overhead and profit from both direct hire and subcontract.** Burden cost of direct labour includes insurance, welfare and other fund and charges associated to labour by regulations.

Include work-hours for the following selected activities:

Installation, calibration, testing, check out, and otherwise field certify the devices. A device is a physical device that has a tag number. This category includes process tubing, instrument air tubing, cable trays, conduits, instrument wire and cable, junction boxes, etc.

Do not include work-hours for:
DCS, software, installation of in-line devices, programming and configuration.

Definitions
The **Installed Quantity** of instrumentation is the amount provided in the project's plans and specifications and does not include any quantity of instrumentation that is used due to rework.

Refer to the section "**Instructions for Computation of Actual Work-Hours, Rework-Hours and Installed Cost**" for a detailed listing of direct hours and their associated costs to be included as well as indirect hours and their associated costs to be excluded.

Overall, please indicate the percentage amount of Instrumentation material and/or equipment procured by the owner. ____ %

Instrumentation	Estimated Productivity			
	None	Quantity (each)	WH	Total Installed Unit Cost ($/ each)
Loops (count)				
Devices (Instruments, count)				
Unit of measure: Dual – Each based on loop check quantity. Each based on field-installed devices. (Instrumentation wire and cable are recorded in Electrical, Section 4.3.)				

Instrumentation	Actual Productivity				
	None	Sub contracted (Yes or No)	Installed Quantity (each)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/ each)
Loops (count)					
Devices (Instruments, count)					
Unit of measure: Dual – Each based on loop check quantity. Each based on field-installed devices. Instrumentation wire and cable are recorded in electrical section (4.3).					

5.6 Equipment

Instructions

Please provide estimated and actual productivity below for the categories appropriate to your project for the installation of equipment.

In the first section of each category include the ***estimated quantity to be installed***, the ***estimated work-hours*** required for the installation and the ***estimated total installed unit cost (TIUC) at the time of project sanction*** (or as soon as available following sanction).

In the second section for each category, provide the ***actual installed neat quantity***, the ***work-hours (including rework),*** and the ***actual total installed unit cost (TIUC).*** Indicate if the work performed for each category was subcontracted or not. If work was both subcontracted and in-house, indicate the type that was more predominant.

Total installed unit cost (TIUC) is defined as the burdened cost of **direct labour, bulk material, final asset equipment, and civil and sitework equipment by pro rata share** including **overhead and profit from both direct hire and subcontract.** Burden cost of direct labour includes insurance, welfare and other fund and charges associated to labour by regulations.

Definitions

The **Installed Quantity** of equipment is the amount provided in the project's plans and specifications and does not include any quantity of equipment that is used due to rework.

Refer to the section "**Instructions for Computation of Actual Work-Hours, Rework-Hours and Installed Cost**" for a detailed listing of direct hours and their associated costs to be included as well as indirect hours and their associated costs to be excluded.

Overall, please indicate the percentage amount of installed equipment procured by the owner. ____ %

Pressure Vessels Field Fab. & Erected	**Estimated Productivity**				
	None	**Quantity (each)**	**WH**	**Total Weight (MT)**	**Total Installed Unit Cost ($/ MT)**
Pressure Vessels					
This includes tray/packed towers, columns, reactors/regenerators, and miscellaneous other pressure vessels. Work-hours should include installation of trays and packing if installed in the field.					

Pressure Vessels Field Fab. & Erected	**Actual Productivity**					
	None	**Sub contracted (Yes or No)**	**Installed Quantity (each)**	**Actual WH (including rework) (hours)**	**Total Weight (MT)**	**Total Installed Unit Cost ($/ MT)**
Pressure Vessels						
This includes tray/packed towers, columns, reactors/regenerators, and miscellaneous other pressure vessels. Work-hours should include installation of trays and packing if installed in the field.						

Pressure Vessels Shop Fab./ Field Erected	Estimated Productivity				
	None	Quantity (each)	WH	Total Weight (MT)	Total Installed Unit Cost ($/ MT)
Pressure Vessels					
This includes tray/packed towers, columns, reactors/regenerators, and miscellaneous other pressure vessels. Work-hours should include installation of trays and packing if installed in the field.					

Pressure Vessels Shop Fab./ Field Erected	Actual Productivity					
	None	Sub contracted (Yes or No)	Installed Quantity (each)	Actual WH (including rework) (hours)	Total Weight (MT)	Total Installed Unit Cost ($/ MT)
Pressure Vessels						
This includes tray/packed towers, columns, reactors/regenerators, and miscellaneous other pressure vessels. Work-hours should include installation of trays and packing if installed in the field.						

Atmospheric Tanks – Shop Fabricated	Estimated Productivity				
	None	Quantity (each)	WH	Total Capacity (MT)	Total Installed Unit Cost ($/ MT)
Atmospheric Tanks – Shop Fabricated					
This includes storage tanks, floating roof tanks, bins/hoppers/silos/cyclones, cryogenic & low temperature tanks and miscellaneous other atmospheric tanks. Include all shop built-up and field-erected tanks. Excluded are field fabricated and assembled tanks.					

Atmospheric Tanks – Shop Fabricated	Actual Productivity					
	None	Sub contracted (Yes or No)	Installed Quantity (each)	Actual WH (including rework) (hours)	Total Capacity (MT)	Total Installed Unit Cost ($/ MT)
Atmospheric Tanks – Shop Fabricated						
This includes storage tanks, floating roof tanks, bins/hoppers/silos/cyclones, cryogenic & low temperature tanks and miscellaneous other atmospheric tanks. Include all shop built-up and field-erected tanks. Excluded are field fabricated and assembled tanks.						

Atmospheric Tanks – Field Fabricated	Estimated Productivity				
	None	Quantity (each)	WH	Total Capacity (MT)	Total Installed Unit Cost ($/ MT)
Atmospheric Tanks – Field Fabricated					
This includes storage tanks, floating roof tanks, bins/hoppers/silos/cyclones, cryogenic and low temperature tanks, and other miscellaneous atmospheric tanks.					

Atmospheric Tanks – Field Fabricated	Actual Productivity					
	None	Sub contracted (Yes or No)	Installed Quantity (each)	Actual WH (including rework) (hours)	Total Capacity (MT)	Total Installed Unit Cost ($/ MT)
Atmospheric Tanks – Field Fabricated						
This includes storage tanks, floating roof tanks, bins/hoppers/silos/cyclones, cryogenic and low temperature tanks, and other miscellaneous atmospheric tanks.						

Heat Transfer Equipment	Estimated Productivity				
	None	Quantity (each)	WH	Total Weight (MT)	Total Installed Unit Cost ($/ MT)
Heat Transfer Equipment					
This includes heat exchangers, fin fan coolers, evaporators, package cooling towers and miscellaneous other heat transfer equipment.					

Heat Transfer Equipment	Actual Productivity					
	None	Sub contracted (Yes or No)	Installed Quantity (each)	Actual WH (including rework) (hours)	Total Weight (MT)	Total Installed Unit Cost ($/ MT)
Heat Transfer Equipment						
This includes heat exchangers, fin fan coolers, evaporators, package cooling towers and miscellaneous other heat transfer equipment.						

Power Generation Equipment	Estimated Productivity				
	None	Quantity (each)	WH	Total (kW)	Total Installed Unit Cost ($/ kW)
Power Generation Equipment					
This includes gas turbines, steam turbines, diesel, and other miscellaneous power generation equipment.					

Power Generation Equipment	Actual Productivity					
	None	Sub contracted (Yes or No)	Installed Quantity (each)	Actual WH (including rework) (hours)	Total (kW)	Total Installed Unit Cost ($/ kW)
Power Generation Equipment						
This includes gas turbines, steam turbines, diesel, and other miscellaneous power generation equipment.						

Other Process Equipment	Estimated Productivity				
	None	Quantity (each)	WH	Total weight (MT)	Total Installed Unit Cost ($/ MT)
Other Process Equipment					
This includes specialty gas equipment, bulk chemical equipment, process equipment, particle extraction (bag houses, scrubbers, etc.), treatment systems (water treatment, etc.), incinerators, and flares/flare systems.					

Other Process Equipment	Actual Productivity					
	None	Sub contracted (Yes or No)	Installed Quantity (each)	Actual WH (including rework) (hours)	Total weight (MT)	Total Installed Unit Cost ($/ MT)
Other Process Equipment						
This includes specialty gas equipment, bulk chemical equipment, process equipment, particle extraction (bag houses, scrubbers, etc.), treatment systems (water treatment, etc.), incinerators, and flares/flare systems.						

Modules & Pre-Assembled Skids	Estimated Productivity				
	None	Quantity (each)	WH	Total weight (MT)	Total Installed Unit Cost ($/ MT)
Modules & Pre-Assembled Skids					
This includes modules (partial units) and complete skids units.					

Modules & Pre-Assembled Skids	Actual Productivity					
	None	Sub contracted (Yes or No)	Installed Quantity (each)	Actual WH (including rework) (hours)	Total weight (MT)	Total Installed Unit Cost ($/ MT)
Modules & Pre-Assembled Skids						
This includes modules (partial units) and complete skids units.						

5.7 Insulation

Instructions

Please provide estimated and actual productivity below for the categories appropriate to your project for the installation of insulation.

In the first section of each category include the ***estimated quantity to be installed***, the ***estimated work-hours*** required for the installation and the ***estimated total installed unit cost (TIUC) at the time of project sanction*** (or as soon as available following sanction).

In the second section for each category, provide the ***actual installed neat quantity***, the ***work-hours (including rework),*** and the ***actual total installed unit cost (TIUC).*** Indicate if the work performed for each category was subcontracted or not. If work was both subcontracted and in-house, indicate the type that was more predominant.

Total installed unit cost (TIUC) is defined as the burdened cost of **direct labour, bulk material, final asset equipment, and civil and sitework equipment by pro rata share** including **overhead and profit from both direct hire and subcontract.** Burden cost of direct labour includes insurance, welfare and other fund and charges associated to labour by regulations.

Definitions

The **Installed Quantity** of insulation is the amount of insulation that is required for the equipment and piping provided in the project's plans and specifications and does not include any quantity of insulation that is used due to rework.

Refer to the section "**Instructions for Computation of Actual Work-Hours, Rework-Hours and Installed Cost**" for a detailed listing of direct hours and their associated costs to be included as well as indirect hours and their associated costs to be excluded.

Equipment

Include work-hours for the following selected activities:
Installation of insulation, jacketing overall vessels, tanks, exchangers, etc.; installation of equipment blankets for pumps, exchangers, etc.; material handling.
Do not include: **scaffolding.**

Overall, please indicate the percentage amount of insulation material and/ or equipment procured by the owner. ____ %

Insulation	Average Thickness (inches)	Estimated Productivity			
		None	Quantity (SM of insulated area)	WH	Total Installed Unit Cost ($/ SM)
Equipment					

Insulation	Average Thickness (inches)	Actual Productivity				
		None	Sub contracted (Yes or No)	Installed Quantity (SM of insulated area)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/ SM)
Equipment						

Piping

<u>This includes work-hours for the following selected activities:</u>
Installation of insulation and jacketing over pipe, valves and fittings; installation of valve insulation blankets and flange insulation.

<u>Instructions for calculation of Weighted Diameter of Piping with Insulation</u> (Hyperlink)

Insulation	Average Thickness (inches)	Estimated Productivity			
		None	Quantity (ELM)	WH	Total Installed Unit Cost ($/ ELM)
Piping					
ELM – Equivalent Linear Meters of insulation applied to piping. Multiple layers count only one time in linear meters.					

Insulation	Average Thickness (inches)	Actual Productivity				
		None	Sub contracted (Yes or No)	Installed Quantity (ELM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/ ELM)
Piping						
ELM – Equivalent Linear Meters of insulation applied to piping. Multiple layers count only one time in linear meters.						

5.8 Module Installation

Instructions

Please provide estimated and actual productivity below for the categories appropriate to your project for field installation of modules. This includes all modules fabricated offsite and transported to the work site as over-dimensional loads requiring special heavy haul/lifting equipment. (Applies to pipe rack modules, process modules and building modules) **Do not include large vessels, towers, columns or drums.**

In the first section of each category include the ***estimated quantity to be installed***, the ***estimated work-hours*** required for the installation and the ***estimated total installed unit cost (TIUC) at the time of project sanction*** (or as soon as available following sanction).

In the second section for each category, provide the ***actual installed neat quantity***, the ***work-hours (including rework),*** and the ***actual total installed unit cost (TIUC).*** Indicate if the work performed for each category was subcontracted or not. If work was both subcontracted and in-house, indicate the type that was more predominant.

Total installed unit cost (TIUC) is defined as the burdened cost of **direct labour, bulk material, final asset equipment, and civil and sitework equipment by pro rata share** including **overhead and profit from both direct hire and subcontract.** Burden cost of direct labour includes insurance, welfare and other fund and charges associated to labour by regulations.

Definitions

The **Installed Quantity** of offsite modules is the number of metric tones (MT) amount indicated in units shown below of offsite modules that are field-installed as provided in the project's plans and specifications.

Refer to Section 4, "**Instructions for Computation of Actual Work-Hours, Rework-Hours and Installed Cost**" for a detailed listing of direct hours and their associated costs to be included as well as indirect hours and their associated costs to be excluded.

Overall, please indicate the percentage amount of modules procured by the owner. ____ %

Pipe Racks Modules	Estimated Productivity			
	None	Quantity (MT)	WH	Total Installed Unit Cost ($/ MT)

Pipe rack module structure may include several components such as structural steel for framework, walkway, platform to support the piping, piping c/w (cooling water) valving. It also may include electrical tray, heat tracing and insulation.

Pipe Racks Modules	Actual Productivity				
	None	Sub Contracted (Yes/No)	Installed Quantity (MT)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/ MT)

Pipe rack module structure may include several components such as structural steel for framework, walkway, platform to support the piping, piping c/w (cooling water) valving. It also may include electrical tray, heat tracing and insulation.

Process Equipment Modules	Estimated Productivity			
	None	Quantity (MT)	WH	Total Installed Unit Cost ($/ MT)

Process Equipment Modules	Actual Productivity				
	None	Sub Contracted (Yes/No)	Installed Quantity (MT)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/ MT)

Building Modules	Estimated Productivity			
	None	Quantity (SM)	WH	Total Installed Unit Cost ($/ SM)

Building Modules are considered as 1 (or more) structural framework structures with a portion (or all of the structure) attached with a building cladding. The structures must be suitable for transport, and fabricated in a location remote to the final location. Examples of modules with buildings are: Electrical MCC buildings, Piping Manifold Buildings, etc.

Building Modules	Actual Productivity				
	None	Sub Contracted (Yes/No)	Installed Quantity (SM)	Actual WH (including rework) (hours)	Total Installed Unit Cost ($/ SM)

Building Modules are considered as 1 (or more) structural framework structures with a portion (or all of the structure) attached with a building cladding. The structures must be suitable for transport, and fabricated in a location remote to the final location. Examples of modules with buildings are: Electrical MCC buildings, Piping Manifold Buildings, etc.

5.9 Scaffolding

Instructions

Please provide estimated and actual productivity for scaffolding:

Enter the ***estimated* total work-hours** required for **scaffolding installation**, the ***estimated* scaffolding work-hours divided by total direct hours**, and the ***estimated* total installed scaffolding cost** including direct labour, materials and equipment cost for installation at the time of project sanction (or as soon as available following sanction).

For ***actual*** productivity, please indicate whether the Scaffolding activity was ***subcontracted or not***. If work was both subcontracted and in-house, indicate which was more predominant.

Last, please provide the ***actual* total work-hours** (including rework) required for scaffolding installation, the ***actual* scaffolding work-hours divided by total direct hours**, and the ***actual* total installed scaffolding cost** which include material, labour and equipment cost for installation from both direct hire and subcontract.

Overall, please indicate the percentage amount of scaffolding procured by the owner. ____ %

Scaffolding	Estimated			
	None	Total Scaffolding Work- Hours	Scaffolding WH/ Total direct hours	Total Installed Scaffolding Cost ($)

Scaffolding	Actual				
	None	Sub contracted (Yes or No)	Total Scaffolding Work- Hours	Scaffolding WH/ Total direct hours	Total Installed Scaffolding Cost ($)

Scaffold Materials

- Free Issue to Contractor
- Rented
- Purchased & Included as part of Scaffold Cost

5.10 Construction Work Hours

Instructions

Please provide estimated and actual Construction Indirect and Direct Work-hours. If either estimated or actual work-hours are not available, please provide your estimated and actual ratio of indirect work-hours to direct work-hours.

Refer to the section "**Instructions for Computation of Actual Work-Hours and Rework-Hours**" in the construction productivity section and "**Instruction for Construction Direct and Indirect Costs"** for a detailed listing of directs and indirects.

Construction Work-hours	Estimated		Actual	
	Total Work-hours	Total Indirect WH/ Total Direct WH	Total Work-hours	Total Indirect WH/ Total Direct WH
Direct				
Indirect				

6. Project Closeout

6.1 Work Hours and Accident Data

To measure Safety Performance and with the goal of achieving zero injuries and illnesses, the recording and classification of occupational injuries and illnesses of all direct hire workers and contractors are reported following the industry guidelines in Canada (WCB and CAPP).

In the spaces below, please record the **Total Number of Fatalities, Lost Time Cases, Medical Aid Cases and First Aid Cases and the Total Number of Restricted Work Cases, Restricted Medical Aid Cases and Restricted First Aid Cases.** With the exception of fatalities, also provide the total number of days away from work for each.

Next, record the number of **Near Misses,** the **Total Site Work-hours (Exposure Hours), Total Number of Employees, the Average Full Time Equivalent,** and the **Number of Hours in Your Normal Work Week.**

Use WCB and CAPP definitions. If you do not track in accordance with these definitions, click Unknown in the boxes below.

<table>
<tr><td colspan="2">Please provide the Total Number of Fatalities from:
________ Workplace occupational injuries or illnesses ◘Unknown
________ Travel-related ◘Unknown</td></tr>
<tr><td>Please provide the Total Number of Lost Time Cases, Medical Aid Cases and First Aid Cases:</td><td>Please provide the total workdays away for Lost Time, Medical Aid and First Aid incidents:</td></tr>
<tr><td>________ Lost Time Cases ◘ Unknown
________ Medical Aid Cases ◘ Unknown
________ First Aid Cases ◘ Unknown</td><td>________ Lost Time Days ◘ Unknown
________ Medical Aid Days ◘ Unknown
________ First Aid Days ◘ Unknown</td></tr>
<tr><td>Please provide the Total Number of Restricted Work Cases, Restricted Medical Aid Cases and Restricted First Aid Cases:</td><td>Please provide the Total Workdays for Restricted Work, Restricted Medical Aid and Restricted First Aid incidents:</td></tr>
<tr><td>________ Total Restricted Work Cases
◘ Unknown</td><td>________ Total Restricted Workdays
◘ Unknown</td></tr>
<tr><td colspan="2">Near Misses
Near Misses are common at many worksites. They do not result in injury-but they may cause property damage. If, say, an employee had been in a slightly different position or place, or the equipment or product placement had been to the left or right, serious injury and/or damages could have resulted. A lot depends on sheer luck and circumstance (Heberle, 1998).
How many near misses occurred? ____________ ◘Unknown</td></tr>
<tr><td colspan="2">Total Site Work-hours (Exposure Hours): ____________________ ◘Unknown
Peak Workforce Number of Employees: _____________________◘Unknown</td></tr>
</table>

6.2 Project Impact

The following section is intended to assess whether environmental or market conditions adversely or positively affected project performance ***beyond the conditions for which you planned.***

Impacts may be assessed ranging from “highly negative”, to “highly positive”. If the factor was adequately planned for, please indicate “As Planned”. If it was not adequately planned for, please indicate the impact, positive or negative. Negative impacts adversely affect the metrics and positive impacts favorably affect the metrics.

Weather Conditions ◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Labour Availability ◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Materials Availability ◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Site Conditions ◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Project Complexity ◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Regulatory Requirements ◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Quality of Field Level Supervision ◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Amount of Scheduled Overtime ◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Amount of Unplanned Overtime ◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	No Effect	Pos	Hi Pos	Hi Neg	Neg	No Effect	Pos	Hi Pos	Hi Neg	Neg	No Effect	Pos	Hi Pos	Hi Neg	Neg	No Effect	Pos	Hi Pos	Hi Neg	Neg	No Effect	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Project Team Experience ◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Craft Labour Skill ◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Engineering Labour Skill ☐ N/A ☐ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK				

Project Team Turnover ☐ N/A ☐ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK				

Detailed Engineering Design Location (Use of Offshore Engineering) ☐ N/A ☐ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK				

Business Market Conditions ☐ N/A ☐ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK				

Coordination with Plant Shutdown ☐ N/A ☐ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK				

Were there other significant factors not listed above that affected performance? ☐ Yes ☐ No

If 'Yes', please list each factor separately and assess the impact using the table below: ☐ N/A ☐ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK				

Please assess below the impact of the **percentage of engineering completed prior to project sanction**

◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Please assess below the impact of the **percentage of engineering completed prior to construction start**

◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

6.3 Workforce Conditions

a) Percentage of workweek by workforce shifts and schedules:

Indicate on average, the predicted and actual percentage of the project's workforce working day, evening and night shifts, by work week schedules. If the actual percentage cannot be calculated, please provide your best assessment. Answer Unknown only if you cannot make a reasonable assessment. Percentages may be indicated in increments of 5 %.

As budgeted in AFE				
Work Schedule (days)	Days		Nights	
4-3	______%	◘ Unknown	______%	◘ Unknown
5-2	______%	◘ Unknown	______%	◘ Unknown
10-4	______%	◘ Unknown	______%	◘ Unknown
11-3	______%	◘ Unknown	______%	◘ Unknown
12-2	______%	◘ Unknown	______%	◘ Unknown
Other	______%	◘ Unknown	______%	◘ Unknown
Total	100 %		100 %	

Actual at project completion				
Work Schedule (days)	Days		Nights	
4-3	______%	◘ Unknown	______%	◘ Unknown
5-2	______%	◘ Unknown	______%	◘ Unknown
10-4	______%	◘ Unknown	______%	◘ Unknown
11-3	______%	◘ Unknown	______%	◘ Unknown
12-2	______%	◘ Unknown	______%	◘ Unknown
Other	______%	◘ Unknown	______%	◘ Unknown
Total	100 %		100 %	

Level of Overtime as % of total field Work-hours

Indicate below the planned and actual percentage of field work-hours classified as overtime.

Planned overtime	Actual overtime
______________% ◘ Unknown	______________% ◘ Unknown

If the ratio of Actual exceeds Planned overtime, please provide the reason why:

____

c) Worker accommodations

Indicate below the planned and actual percentage of workers living in camps and with living out allowance (LOA).

Planned % of workers in camps	Actual % of workers in camps
______________% ◘ Unknown	______________% ◘ Unknown

Planned % of workers with LOA	Actual % of workers with LOA
______________% ◘ Unknown	______________% ◘ Unknown

d) Peak construction work force

Indicate the peak construction work force planned and achieved for this project by inputting the maximum number of working personnel at the jobsite at one time:

Planned Peak Work Force	Actual Peak Work Force
______________ ◘ Unknown	______________ ◘ Unknown

e) Indicate as a percentage below the planned and actual methods utilized by personnel for travel to the worksite.

Mode of Travel	Planned	Actual
Bus	__________% ◘ Unknown	__________% ◘ Unknown
Air	__________% ◘ Unknown	__________% ◘ Unknown
Personal Vehicle	__________% ◘ Unknown	__________% ◘ Unknown
Other	__________% ◘ Unknown	__________% ◘ Unknown
Total	100 %	100 %

f) Percentage of winter work:

What percentage of **winter work was performed in outdoor conditions from October 15 to April 15?** If the actual percentage cannot be calculated, please provide your best assessment. Answer Unknown only if you cannot make a reasonable assessment.

Planned Outdoor Work in Winter	Actual Outdoor Work in Winter
______________% ◘ Unknown	______________% ◘ Unknown

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Vita

Arpamart Chanmeka was born in Bangkok, Thailand, on June 27, 1976, the daughter of Sampao Chanmeka and Patima Chanmeka. In June, 1997, she obtained Bachelor of Engineering in Civil Engineering with honors from Mahanakorn University of Technology in Bangkok, Thailand. In April 1999, she obtained a Master of Engineering in Civil Engineering from Asian Institute of Technology in the field of Structural Engineering. In June, 1999, she accepted a position as a project engineer IV at the Department of Drainage and Sewerage, Bangkok Metropolitan Administration (BMA). She was responsible for designing structures and managing constructions on engineering, procurement, and construction (EPC) projects for various drainage, sewerage and flood control systems. In the following years, she served in a higher position as a project engineer V. In September 2004, she entered the Graduate School at the University of Texas at Austin to pursue her doctorate in Civil Engineering with a specialization in Construction Engineering and Project Management. Since 2004, she has been working with the Benchmarking & Metrics team at the Construction Industry Institute (CII). At CII, she has been responsible for CII large project benchmarking activities and analysis of CII annual safety data. Her primary research area focuses on project performance assessment and benchmarking initiative for Alberta major projects

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